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REPORT OF THE INTERNATIONAL JOINT COMMISSION, UNITED STATES AND CANADA ON THE POLLUTION OF THE ATMOSPHERE IN THE DETROIT RIVER AREA

International Joint Commission-
United States and Canada

1960

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Report

OF THE

INTERNATIONAL JOINT COMMISSION

UNITED STATES AND CANADA

ON THE

Pollution of the Atmosphere
in the
Detroit River Area

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	Donald M. Stephens
Harry J. Donohue, Secretary	D.G. Chance, Secretary

LETTER OF TRANSMITTAL

The following letter was sent to the Secretary of State, Washington, D.C., by the secretary of the United States Section of the International Joint Commission and to the Secretary of State for External Affairs, Ottawa, Canada, by the secretary of the Canadian Section of the International Joint Commission:

27 June 1960

Sir,

I have the honor to transmit to you the "Report of the International Joint Commission, United States and Canada, on the Pollution of the Atmosphere in the Detroit River Area", dated 31 May 1960.

Under the reference of 12 January 1949, the Commission was requested by the Governments to inquire into and report upon the pollution of the air in the vicinity of the cities of Detroit and Windsor on either side of the international boundary in the area of the Detroit River. A copy of the report of the Technical Advisory Board of 1959, addressed to the Commission, is appended and forms part of the report of the International Joint Commission.

Yours sincerely,

Harry J. Donohue
Secretary, United States Section

David G. Chance
Secretary, Canadian Section

Report of

THE INTERNATIONAL JOINT COMMISSION

United States and Canada

On The

Pollution of the Atmosphere

In The

Detroit River Area

The Secretary of State for the Government of the United States and the Prime Minister for the Government of Canada, on January 12, 1949, made the following Reference to the International Joint Commission through identical letters addressed to United States and Canadian Sections of the Commission:

"I have the honor to inform you that representations have been made to the Governments of the United States and Canada to the effect that the air in the vicinity of the cities of Detroit and Windsor on both sides of the international boundary in the area of the Detroit River, is being polluted by the discharge of smoke, soot and fly ash, in quantities sufficient to be detrimental to the public health, safety and general welfare of the citizens of both countries in this area. It has further been represented to the two Governments that vessels passing through the Detroit River are a source of this pollution. Pursuant to the provisions of Article IX of the Boundary Waters Treaty, signed January 11, 1909, the two Governments have agreed to a joint reference of this matter to the International Joint Commission. The Commission is requested to enquire into, and to report to the two Governments upon the following questions:

1. Is the air over, and in the vicinity of, the cities of Detroit and Windsor, on either side of the international boundary, being polluted by smoke, soot, fly ash, or other impurities, in quantities detrimental to the public health, safety or general welfare of the citizens, or to property interests on either side of the international boundary line?

2. If the foregoing question, or any part thereof, is answered in the affirmative, to what extent are vessels plying the waters of the Detroit River, or any of them, contributing to this pollution; what other major factors are responsible and to what extent?

3. If the Commission should find that vessels plying the waters of the Detroit River, or any of them, are responsible for air pollution to an extent detrimental to the public health, safety or general welfare of the citizens, or to the property interests on either side of the international boundary line,

   (a) what preventive or remedial measures would, in its judgment, be most practical from the economic, sanitary and other points of view?

   (b) what would be the probable cost of such measures?

   (c) by whom should such cost be borne?

For the purpose of assisting the Commission is making the investigations and recommendations provided for in this reference, the two Governments, upon request, will make available to the Commission the services of engineers and other specially qualified personnel of their respective Governments, and such information and technical data as may have been acquired by such Governments or as may be acquired by them during the course of the investigation.

The Commission should submit its report and recommendations to the two Governments as soon as practicable."

APPOINTMENT OF THE TECHNICAL ADVISORY BOARD

Following receipt of the Reference, the Commission, in April 1949, appointed a board of three experts from the United States and three from Canada from personnel made available by the two Federal Governments and the Province of Ontario to act as technical advisers and supervise the conduct of the investigation. Membership of this Technical Advisory Board was increased from six to eight in April 1954, by the addition of two medical experts, one representing the Detroit Department of Health and the other from the Department of National Health and Welfare, Ottawa.

As presently constituted the Technical Advisory Board consists of - for Canada - Dr. Morris Katz, Chairman, Dr. Clare M. Jephcott, Dr. Thomas H. Patterson, and Mr. J. Ross Menzies; for the United States - Mr. Arthur C. Stern, Chairman, Dr. Charles P. Anderson, Dr. Louis C. McCabe, and Mr. John F. Barkley. Previous Board chairmen and members were - for Canada - Members - Dr. E. A. Watkinson and Dr. A.E.R. Westman; for the United States - Chairmen - Dr. A. T. Rossano, Jr., Mr. G.D. Clayton, and Mr. L.M. Fisher and Members - Dr. H.A. Schrenk, Mr. C.H. Atkins, and Mr. P.D. Haney. For the United States the present Secretary to the Board is Dr. Roy O. McCaldin. The former Secretary was Mr. Jean J. Schueneman.

DESCRIPTION OF THE AREA

This report covers the area specified broadly in the Reference as that located in the vicinity of Detroit and Windsor, including the Detroit River. On the United States side of the international boundary this includes all of Wayne County and the southern portions of Macomb and Oakland Counties in Michigan. On the Canadian side this includes the western portion of Essex County in Ontario. This is a highly industrialized area with an estimated population in 1955 of nearly 3.5 million. There are 6,400 industrial establishments in the area employing about 750,000 persons; of these, about 30,000 persons are employed in 450 industries in the Windsor area. Most of the industries are in Wayne County, Michigan, with the heaviest industrialization along the Detroit and Rouge Rivers. The predominant industries are automobile manufacture, ordnance, primary metals, fabricated metals, and machinery.

ORGANIZATION AND PROCEDURE OF THE INVESTIGATION

Comprehensive scientific and engineering studies and field surveys of the atmospheric pollution problem required for the purpose of the Reference were organized by the Technical Advisory Board and carried out through the cooperation of the appropriate Federal, State and Provincial, Municipal and other agencies concerned, including the Lake Carriers' and Dominion Marine Associations. A detailed account of the investigation is given in the report of the Technical Advisory Board which is appended and forms part of this report.

In order to provide the necessary information under the terms of the Reference, studies were carried out to determine the sources, nature and concentration levels of major atmospheric contaminants resulting from combustion of fuels and industrial processes, the influence of meteorological factors on dispersion and diffusion of these contaminants, the extent of transboundary flow of pollution and the effects of pollution upon public health and welfare, vegetation and visibility. The problem of excessive smoke emission from vessels plying the Detroit River was given major consideration and, in accordance with the terms of the Reference, studies were also carried out to determine the control and remedial measures necessary to abate pollution from this source, including the probable cost of such measures.

Smoke measurements based on the Ringelmann Chart method were commenced in July 1949 and have been continued in each navigation season since then. The Canadian Section of the Board has had the main responsibility for the compilation of these data which cover from 450 to 650 vessels in some 2,500 to 4,500 passages of the river during a navigation season. Annual reports concerning the smoke performance of vessels in relation to firing equipment have been distributed to vessel owners and operators on the Great Lakes, to the Dominion Marine and Lake Carriers' Associations, to municipalities along the Detroit River and to other interested agencies.

In 1952, the Commission approved, on an annual basis, the establishment of "smoke emission objectives" that define the limits of smoke in terms of Ringelmann number and time for various types of fuel-burning equipment installed on vessels passing through the Detroit River. In the succeeding years these objectives were made progressively more stringent until 1955. These objectives and the frequent dissemination during the navigation season to ship owners or operators of information on smoke emission observations made on their vessels have formed the foundation of a voluntary control program that has had the active cooperation and support of a large majority of those concerned, including the vessel owner associations and the air pollution control officers of municipalities along the Detroit River.

Three public hearings have been held by the Commission to assess the results of the vessel smoke studies and progress in the voluntary control program, to obtain information on remedial measures and estimates of costs of automatic fuelburning installations to alleviate air pollution from vessels, to determine the time required for the institution of necessary pollution control measures and to obtain the views of all interested parties towards proposals for setting appropriate emission standards for pollution control. These hearings took place as follows:

Detroit, Michigan	October 18 & 19, 1950
Detroit, Michigan	June 5, 1953
Detroit, Michigan	February 19, 1958

FINDINGS

The findings of the Commission, after consideration of the results of the investigation and the evidence presented at the Commission's hearings, are outlined below.

NATURE AND EXTENT OF THE POLLUTION PROBLEM:

The extensive scale and variety of land-based industrial and commercial operations, the large amount of traffic on land and water, as well as the use of large quantities of fuel for domestic and industrial purposes and other activities of the public, generate large quantities of atmospheric contaminants of many varieties. These consist of smoke, soot, fly ash, and other particulate matter, sulfur dioxide, oxides of nitrogen, aldehydes, and other gaseous and vapor contaminants. The consumption of solid fuel in land-based industrial, commercial, and domestic fuel-burning equipment was established in 1954-1955 to total 12,244,000 tons annually. At the same time the total annual consumption of fuel oil and natural gas was 2,920,000 and 3,832,500 tons respectively. In contrast to this, the solid fuel consumption by vessels during passages of the Detroit River in an average navigation season has been estimated at about 108,000 tons. Thus, over the eight month navigation season this fuel consumption by vessels represents only about 1.5 percent of the total solid fuel burned in the study area in a comparable period. However, the land-based sources are distributed over a comparatively large area within the approximately 900 square mile region under study, whereas the smoke and fly ash deposition on land from vessels is centered in a narrow belt adjoining the Detroit River.

The total emissions to the atmosphere of contaminants in 1956 were estimated to be about 4,000 tons per day of gases such as sulfur oxides, nitrogen oxides, acids, organics and unspecified gases, and 1,270 tons of solids. These totals do not include carbon monoxide and carbon dioxide or the particulate matter discharged from blast furnaces, steel furnaces, or iron and steel foundries, as these emissions could not be estimated with sufficient accuracy. Of this total, industry and commerce contributed 1,980 tons per day in the form of gaseous and vapor contaminants and 1,040 tons in the form of solids. The remainder came from other sources such as fuel used in domestic heating equipment and motor vehicles.

The results of environmental studies indicate that the most heavily polluted areas lie close to the Detroit River and adjacent to major industrial operations. The amount of dust deposition is about two to three times higher in industrial-commercial districts than in residential sections of Detroit or Windsor. It was found that the Windsor high pollution area contained monthly mean loadings of air-borne particulate matter that were about two to six times the mean concentrations found at Harrow, Ontario, about 25 miles distant from the Detroit River.

Mean concentrations of sulfur dioxide pollution in the industrial areas of Windsor were found to be about five to more than seven times the mean concentrations at points in Ontario 15 to 25 miles distant from the Detroit River. The maximum monthly mean concentration in the industrial part of Windsor was about ten times the maximum monthly mean concentration of sulfur dioxide at Harrow, Ontario. In Detroit, the mean sulfur dioxide levels in the high pollution area were about twice as high as the level in the Windsor high pollution area.

EFFECTS OF THE POLLUTION

The possible effects of air pollution on health were investigated in a two-year pilot study of groups of households in a number of residential areas on both sides of the Detroit River. During this period, the concentrations of principal air contaminants in the study area were determined. It was found that the monthly rates of sickness in all areas under study followed a similar chronological pattern, although at differing levels. However, two areas in Detroit showed a pattern of sickness rates that differed substantially from each other. The rates in the high pollution area were generally at a greater level than those in the low pollution area. In other groups of households in Detroit and in Windsor, the results were inconclusive. Thus, some effect on health was demonstrated althrough the elucidation of the quantitative relationship between atmospheric contamination and sickness experience and health clearly requires further study.

General observations on vegetation throughout the study area were carried out by a survey team in an attempt to determine the nature and extent of injury from air pollution, particularly in the vicinity of probable sources of pollutants. The work was complicated by the fact that present knowledge of the effects of urban air pollution on vegetation is incomplete. The presence in the urban atmosphere of various particulate and gaseous pollutants tended to complicate the evaluation of nonspecific symptoms on the leaves of plants. In the case of nonspecific complaints of poor growth in urban areas, inadequate soil moisture, poor drainage, nutritional imbalances and cultural practices may be contributing factors. Although the results of the surveys did not indicate the presence of a general repressive effect on vegetation due to air pollution, injury to certain species of vegetation was found on both sides of the Detroit River area in the vicinity of some local land-based sources of contamination.

A study of solar illumination in the City of Windsor and at Harrow, Ontario, about 25 miles south of the Detroit River, has shown that the daylight in Windsor is reduced by the presence of aerosol pollutants that attenuate the solar radiation by reflection, scattering, and absorption. The measurements at the town of Harrow are also affected by the presence of particulate pollution, of which a substantial fraction very probably originated in the Detroit-Windsor area. However, if the monthly mean illumination at Windsor is expressed as a percentage of that at Harrow, the monthly values range from a low of 80 percent in December to 96 percent in September, with a yearly mean of 92 percent. Larger differences in illumination between Windsor and Harrow have been obtained on days of relatively high pollution. The reduction in ultraviolet radiation would be greater than that for visual light. It is the ultraviolet component of light which kills bacteria and which has been shown to help prevent rickets in improperly nourished children.

Measurements of visibility have been made in Detroit with a transmissometer. Reduced light transmittance was found to be associated with winds from directions tending to bring contaminated air from major industrial sources of pollutants to the observation site. The highest visibility occurred when winds were from directions in which were located residential areas and small business establishments.

The adverse effect on property through deposition of smoke and fly ash, the action of acid gases and the soiling of surfaces by aerosol pollutants represent economic loss. This includes damages to fabrics, household equipment, merchandise, buildings, metal products and other exposed materials. It is difficult to place an exact estimate on all the economic effects resulting from contaminated air because of the varied nature of such losses and due to the lack of pertinent statistics. However, within certain limits, some relative estimates may be made with regard to the Greater Detroit-Windsor area, based on information derived from surveys of the U.S. Department of Commerce, the U.S. Geological Survey, and other sources.

After consideration of the levels of dustfall, air-borne particulate matter, sulfur dioxide, and other contaminants in the study area, the Commission's Board of Technical Advisers estimated that the economic loss from air pollution from all sources, that is, both land based and vessels, averages at least $20 per capita per year. For the approximately 3.5 million inhabitants of the Detroit River area, the total annual loss from all sources would amount to approximately 70 million dollars.

The City of Detroit has undertaken an extensive program of reconstruction and rehabilitation of the downtown area, with the erection of many modern public and office buildings. The replacement of old buildings in the waterfront area by new construction with appropriate park and other landscape development is an important feature of the plan which involves expenditures of hundreds of millions of dollars. These new developments are particularly susceptible to damage from excessive smoke from both nearby land installations and from vessels. Improvement in smoke emission from all sources is needed to protect them. Similar considerations on a more limited scale are applicable to the City of Windsor.

A number of recreational areas are located in the region under reference, including those situated along the shores of the Detroit River and on islands in the river. Contamination of these areas by smoke detracts from their value and desirability.

FLOW OF POLLUTION ACROSS THE INTERNATIONAL BOUNDARY

Factors affecting transboundary pollution include the geographical contours of the Detroit River, the location of major industrial sources, including vessel traffic and the wind flow pattern in the study area. Thus, with the prevailing wind movement from between west and north, the pollutants originating from sources within the United States are swept across the boundary into Canada. On the less frequent occasions when the wind direction is from south to east sectors of the compass air pollutants originating on the Canadian side are carried over into the United States. With wind from other points of the compass the transboundary pollution will depend upon the location of particular major sources in relation to the contours of the Detroit River.

The actual transboundary flow of air-borne particulate pollution has been measured at pairs of sampling stations located at opposite points along both banks of the Detroit River from the southern part of Grosse Isle to the eastern end of Belle Isle. The measurements were correlated with meteorological observations in the form of a wind rose analysis. This study was carried out in the winter of 1954 at a time when there was very little vessel traffic on the river. It was found that a considerable amount of particulate pollution from sources within the River Rouge-Zug Island area of the United States passed over the Ojibway area in Canada. Lesser transboundary pollution was noted at several points along the river where there was evidence of a somewhat greater differential flow from the United States into Canada than vice versa. During the navigation season this transboundary flow is augmented by the emissions from vessels. It is clear that air circulation across the boundary is such that any substantial source of pollution on either side is a matter of concern to both countries.

THE VESSEL SMOKE PROBLEM

The type of vessel found most suitable for navigation in the Upper Lakes and Lake Erie and for accommodating the maximum volume of cargo is of 10,000 tons capacity or more and is long and narrow and not designed for transocean service. The "canaler" type required heretofore to navigate the canals of the St. Lawrence is much smaller, of 2,000 to 3,000 tons capacity, and has been used to trans-ship freight from bulk carriers to ocean-going vessels. It is anticipated that, with the opening or the St. Lawrence Seaway and the resultant ready access of the Lower St. Lawrence to Great Lakes bulk carriers, there will be an increased use of the Upper Lakes by ocean-going vessels and modification of some of the Upper Lakes vessels to make them suitable for ocean service.

At the close of 1959, the Great Lakes fleet consisted of about 702 vessels with a gross registered tonnage of about 3,500,000 tons, of which 432 vessels were of United States registry with a gross tonnage of 2,546,876 and 270 vessels were of Canadian registry with a gross tonnage of 958,341. The carrying capacity of the fleet reached the 5,000,000 gross ton mark in 1954 for the first time in history, and since has fluctuated slightly above or below this figure. About three-quarters of the total tonnage of cargo is carried by United States vessels. On the Detroit River, in an average navigation season, about 120,000,000 short tons of cargo are carried by vessels in over 28,000 passages of the river.

A survey of the various types of firing equipment installed on 199 Canadian and 417 United States vessels operating on the Detroit River indicated that about 45 percent of the Canadian vessels were equipped with oil firing or diesel engines as compared with only 25 percent of the United States vessels. However, in the vessels using coal for fuel, the United States fleet contains about a five-fold greater percentage of vessels equipped with automatic stoking devices than the Canadian fleet. Since the winter lay-up season of 1951-1952, forty-three hand-fired vessels of both fleets have been equipped with underfeed stokers. This conversion, after a relatively slow start, has been accelerated within the last few years. However, approximately 41 percent of the Canadian vessels and 34 percent of the United States vessels are still hand-fired and, in general, such vessels cannot burn coal without generating objectionable amounts of smoke.

Many of the vessels plying the Great Lakes were built in the first decade of this century. Of the total number of Canadian vessels, 37 percent are over 30 years old, and of the United States vessels about 50 percent are more than

45 years of age. However, the trend in new vessel construction, particularly on the Canadian side, has been to diesel and oil fired equipment which can operate without excessive smoke emission.

Vessels of European registry are playing a significantly increasing part in Great Lakes commerce. In 1954, such vessels numbered 100 and completed 267 trips; by 1958 this number had increased to 181 and the completed trips totalled 502. This traffic is expected to increase as a result of the opening of the St. Lawrence Seaway. However, this foreign fleet is a relatively modern one since most of the vessels are less than 10 years old and about 80 percent are powered by diesel engines.

A very large amount of information has been accumulated since 1949 on the smoke emission of vessels plying the Detroit River. Black smoke drifting shoreward from passing vessels was a familiar sight in the early years of this study. Thus, in 1949 and 1950, the discharge of objectionable smoke of No. 3 Ringelmann or darker was observed in over 85 percent of vessel passages. In these years such excessive smoke was emitted more than 50 percent of the time. The seriousness of this situation was emphasized by the large volume of vessel traffic carried on this relatively narrow waterway.

The voluntary smoke control program that has been in effect since 1952 has resulted in a major reduction in air pollution from vessels on the Detroit River. The duration of excessive smoke of No. 3 Ringelmann or darker has been decreased from the high level of 53.6 percent of the time in 1949 to only about 11.8 percent over the four-year period 1954-1957. Conversely, over the same time period, the frequency of persistence of clear conditions or No. 1 Ringelmann has increased from 18.8 to about 75 percent of the time. However, it has been evident over the last several years that hand-fired coal-burning vessels cannot consume fuel with the required efficiency to meet reasonable smoke emission standards. In fact, these hand-fired vessels now constitute the core of the vessel smoke problem and further progress can only be achieved by the large scale conversion of such hand-fired equipment to automatic firing. The lack of improvement in the smoke performance of vessels that has been noted since 1955 is highly significant and indicates that the limit of effectiveness of the voluntary control programs has been reached and that further measures are necessary for more effective control of vessel smoke.

CONCLUSIONS

The conclusions of the Commission with regard to each of the questions contained in the Reference are as follows:

Question 1.

> Is the air over, and in the vicinity of, the cities of Detroit and Windsor, on either side of the international boundary, being polluted by smoke, soot, fly ash or other impurities, in quantities detrimental to the public health, safety or general welfare of the citizens or to property interests on either side of the international boundary line?

The Commission finds that the air under reference is being polluted on both sides of the international boundary to an extent that is detrimental to the general welfare of the citizens in communities along the Detroit River and to property interests.

Question 2.

> If the foregoing question, or any part thereof, is answered in the affirmative, to what extent are vessels plying the waters of the Detroit River, or any of them, contributing to this pollution; what other major factors are responsible and to what extent?

The Commission finds that vessels plying the waters of the Detroit River, particularly the hand-fired coal-burning vessels, contribute seriously to pollution of the air over, and in the vicinity of, the cities of Detroit and Windsor and other communities along the river on both sides. Although the voluntary control program instituted by the Commission through the Technical Advisory Board has effected a considerable improvement in smoke pollution from vessels, as compared with conditions prior to 1954, the excessive smoke emission from about 25 percent or more of the vessels, nearly all in the hand-fired class, is still a source of pollution that is detrimental to the general welfare of the citizens and to property interests on both sides of the international boundary. Notwithstanding the voluntary control program, the number of vessels that have been observed to discharge dark or black smoke of Nos. 3, 4, and 5 Ringelmann in over 50 percent of their Detroit River passages have ranged from 143 to as high as 209 in the years since 1955. These violations of the voluntary standards of smoke emission represented 28 to 35 percent of all observed passages of the river.

The Commission finds that other major factors responsible for the detrimental pollution are the relatively high levels of dustfall, airborne particulate impurities and gaseous contamination, such as sulfur dioxide from numerous industrial installations and other sources on land, including the combustion products of large quantities of fuel. The concentrations are influenced by variable meteorological factors and show both diurnal and seasonal effects. A contributing factor to the levels of pollution is the transfer of pollution from each side of the boundary to the other along the Detroit River, much the most serious effect involving the flow of impurities from the River Rouge-Zug Island area of the United States to the Canadian side.

Industrial, domestic and transportation activities on land contribute to the overall pollution of the air to a much greater extent than vessels plying the river if consideration is given only to average pollution levels over the entire study area. However, air pollution from vessels represents an intermittent but visible source that is more evident in its effects in a narrow belt adjoining both sides of the Detroit River than in areas farther inland. The vessels ply the river in relatively close proximity to residential, recreational, and civic land developments that are thus subjected to the harmful influence of drifting smoke and fly ash, readily identifiable as to their source.

Question 3.

> If the Commission should find that vessels plying the waters of the Detroit River, or any of them, are responsible for air pollution to an extent detrimental to the public health, safety or general welfare of the citizens, or to the property interests on either side of the international line.
>
> (a) what preventive or remedial measures would, in its judgment, be most practical from the economic, sanitary and other points of view?
>
> (b) what would be the probable cost of such measures?
>
> (c) by whom should such cost be borne?

In the judgment of the Commission a limit has been reached under the voluntary control program in the abatement of air pollution from vessels plying the Detroit River. It is clear that continued surveillance should be maintained and that some form of continuing regulation be enforced to ensure that there is no appreciable lapse in the performance achieved under the voluntary control program. For landbased sources, industries operating within the corporate limits of the cities of Detroit and Windsor and many other municipalities within the Detroit River area are subject to air pollution control regulations as outlined in the chapter on Legislation and Regulation in the appended report of the Technical Advisory Board. Within the United States the provisions of such regulations apply equally to railway and other forms of transportation on land. Within Canada the control of air pollution from railway operations comes under the jurisdiction of the Board of Transport Commissioners for Canada.

The Commission is convinced that advances in technology have made it possible, by use of modern fuel-burning equipment, to burn both solid and liquid fuels efficiently and thus prevent the discharge of excessive smoke. The great majority of vessels equipped with automatic firing installations such as diesel engines, oil-fired furnaces, under-feed and spreader stokers have shown satisfactory progress in smoke abatement and will have little difficulty in avoiding excessive smoke emission. The main problem in the control of atmospheric pollution from shipping is that presented by the hand-fired vessel.

Most of the hand-fired vessels on the Great Lakes are equipped with Scotch marine boilers, although some have watertube boiler installations. Such vessels could burn coal more efficiently and with less objectionable smoke by conversion to automatic firing. Another possible solution for hand-fired vessels is conversion to oil-firing. Most of the larger vessels containing water-tube boilers and fired by coal are equipped with spreader stokers. The principal economic problem associated with eliminating excessive smoke from vessels of the Scotch marine boiler class is the cost of conversion to either automatic stoking or oil-firing.

With respect to Detroit River shipping, there are approximately 200 hand-fired vessels equipped with Scotch marine boilers. Of the 200 vessels, some are small "canalers" of about 2,000 to 3,000 tons gross cargo-carrying capacity, but the proportion of these to the total shipping is somewhat lower in the Detroit River than in the lower reaches of the Great Lakes system. The problem of converting "canalers" or replacing them with vessels of greater cargo capacity is, therefore, less acute in the Detroit River than in the lower Lakes.

Since the winter lay-up period of 1951-1952, more than 40 hand-fired vessels have been converted to underfeed stoker firing under the voluntary control program. In 1955, the costs for stoker, automatic controls, fuel handling system and installation were about $60,000 to $65,000 for a six-furnace vessel, and about $45,000 to $50,000 for a four-furnace vessel. Estimates of current costs run as high as $100,000 for a six-furnace vessel. To offset this capital cost, certain savings may be accomplished through a reduction in coal consumption of as much as nine or ten percent, a decrease in the labor force, or both. Thus, for a six-furnace hand-fired vessel, the normal complement of six firemen and coal passers can be reduced to three on conversion to underfeed stoking.

A number of vessels have been converted from hand-firing to oil-firing and many of the newly commissioned vessels in recent years have been equipped with oil burners. For a six-furnace vessel, the investment for burners, automatic controls, fuel storage and installation varies from $80,000 to $100,000. Although fuel costs are, of course, higher for oil-firing, substantial savings can be effected through increased average speed, which may enable the vessel to make at least one extra trip per season; through reduction in fuel bunker space by 50 percent, which permits a corresponding increase in cargo space; and through a substantial decrease in the labor force of firemen and coal passers.

The Commission is of the opinion that the possible savings mentioned above are substantial and that, for vessels of sufficient cargo-carrying capacity, the costs of conversion to either automatic stoking or oil firing would be repaid within a reasonable number of years. At an average cost of about $75,000 per vessel, the above conversion program for 200 vessels would entail a total expenditure of about $15,000,000.

For vessels of small cargo carrying capacity, designed within the limits set for navigating the St. Lawrence River fourteen foot canals, the foregoing considerations do not apply because they only carry one man per shift to fire furnaces so that no laborsaving is possible after conversion. Formerly these "canalers", with a carrying capacity of 2,000 to 3,000 tons, filled an economic need. Some seven or eight canalers were required to keep a single large Upper Lakes bulk carrier in operation and they have been a significant factor in the Great Lakes shipping economy, particularly with respect to the Canadian fleet. With the completion of the St. Lawrence Seaway, however, the significance of the canaler in the economy is greatly reduced, and it is expected that they will be withdrawn from this service, perhaps within a few years, or replaced by vessels better adapted to the changed operating conditions. Excessive smoke emission by canalers is, therefore, an interim problem that will disappear in a few years and for which no economical remedial measures are available.

For the larger hand-fired vessels that will remain in service in the face of competition from other Great Lakes and foreign vessels, there are at hand practical remedial measures for control of smoke and fly ash. However, as there are insufficient resources available in equipment and manufacturing facilities to meet the problem of the immediate conversion of large numbers of hand-fired vessels to more modern firing methods, a reasonable time period should be allowed for the installation of such equipment.

The Commission considers that the costs of the remedial measures necessary for abatement of air pollution from vessels should be borne solely by the owners of such vessels.

With respect to air pollution originating from sources other than vessels, the Commission believes that there is adequate legal and administrative authority in each country to enforce proper control of the emission of objectionable waste products. With regard to air pollution from vessels, the existing legislation is applicable only to certain limited aspects of the problem and consideration should therefore be given in each country to the additional legislation necessary to ensure adequate control of pollution from vessels.

Application of the Detroit and Windsor smoke ordinances to ship in transit in the Detroit River has to date proved impractical. This is because the ship channels in the Detroit River cross and recross the boundary between the United States and Canada, and ships can pass from one jurisdiction to another so rapidly that ordinance violations are at times impossible to establish. A minimum observation period exceeding four minutes is required to establish a violation of these ordinances. In addition, as most of the ships do not stop in Detroit or Windsor, the service of notice of violation on the appropriate persons and the appearance of such persons for hearings or trials are difficult or impossible to effect. For these reasons, the Commission believes that procedures must be found to overcome impediments to enforcement of smoke emission standards on the Detroit River

RECOMMENDATIONS

(1) The Commission recommends that the objectives for emission of smoke from vessels plying the Detroit River as set forth in this report be adopted by the two Governments as the criteria to be met in maintaining the atmosphere over, and in the vicinity of, these boundary waters in satisfactory condition. Furthermore, the Commission recommends that appropriate action be taken in each country to ensure that these objectives are met.

OBJECTIVES FOR EMISSION OF SMOKE FROM VESSELS PLYING THE DETROIT RIVER

(a) The objective for all vessels, except for an interim period for hand-fired vessels, shall be:

No smoke, the shade or appearance of which is equal to or darker than No. 2 of the Ringelmann Chart shall be emitted, except that smoke the shade or appearance of which is equal to but not darker than No. 2 of the Ringelmann Chart for a period or periods aggregating not more than 4 minutes in any 30 minutes shall be permitted;

(b) For an interim period determined as recommended below, the objective for hand-fired vessels shall be:

No smoke, the shade or appearance of which is equal to or darker than No. 3 of the Ringelmann Chart shall be emitted, except that smoke the shade or appearance of which is equal to but not darker than No. 3 of the Ringelmann Chart for a period or periods aggregating not more than 9 minutes in any 30 minutes shall be permitted;

(c) For the purpose of grading the shade or appearance of smoke, the Ringelmann Chart as published and used by the U.S. Bureau of Mines, shall be the standard, but the use of any other chart or device having shades equivalent to those of the Ringelmann Chart shall be acceptable.

(2) The Commission recommends that these objectives be applicable to vessels in transit in the area under reference.

(3) The Commission recommends that at such time as the two Governments shall determine that it would be in the best interests of Canada and the United States to do so, the objectives set forth herein be amended by deleting

therefrom the interim exception in favor of hand-fired vessels.

(4) As questions relating to the legal, administrative and other details of enforcement require further study for resolution at various government levels, the Commission recommends that each Government develop legal and administrative procedures for dealing with noncompliance with the regulations of the several jurisdictions with respect to air pollution from vessels; develop appropriate methods for establishing proof of such noncompliance; study and resolve related questions such as the definition of the jurisdictions of courts concerned with the enforcement of regulations which now exist or may be adopted, and of extenuating circumstances under which deviations from such regulations should be permitted.

(5) As a procedure to ensure that there shall be no relaxation of existing efforts to abate air pollution from vessels on the Detroit River in any interim period that may elapse until implementation of effective regulations or the resolution of legal, administrative and jurisdictional matters, or until appropriate machinery has been set up to establish the control of air pollution on a satisfactory working basis, the Commission recommends that it be specifically authorized by the two Governments to establish and maintain continuing surveillance of air pollution from vessels in the Detroit River area through a board appointed by the Commission. In carrying out this surveillance, the Commission would continue to conduct a program of observation and control of vessel smoke emission on the Detroit River on a voluntary basis in cooperation with governmental and shipping interests concerned.

(6) In order that owners and operators, captains and engineers of vessels may be assisted in their efforts to comply with emission limitations on a uniform basis, the Commission recommends that appropriate jurisdictions be encouraged to adopt with respect to vessels, regulations which conform to the objectives herein recommended to the two Governments so that vessels will be subject to uniform regulations.

(7) All costs incurred for vessels to meet the objectives herein recommended should be borne by the owners of the vessels.

Signed at Ottawa, Canada the 31st day of May, 1960

Eugene W. Weber

A. G. L. McNaughton

Francis L. Adams

J. Lucien Dansereau

D. M. Stephens

REPORT

of the

TECHNICAL ADVISORY BOARD

to the

INTERNATIONAL JOINT COMMISSION
UNITED STATES AND CANADA

on

AIR POLLUTION IN THE DETROIT-WINDSOR AREA

1959

WASHINGTON OTTAWA

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE

DIRECTOR
Robert A. Taft Sanitary Engineering Center
4676 Columbia Parkway
Cincinnati 26, Ohio

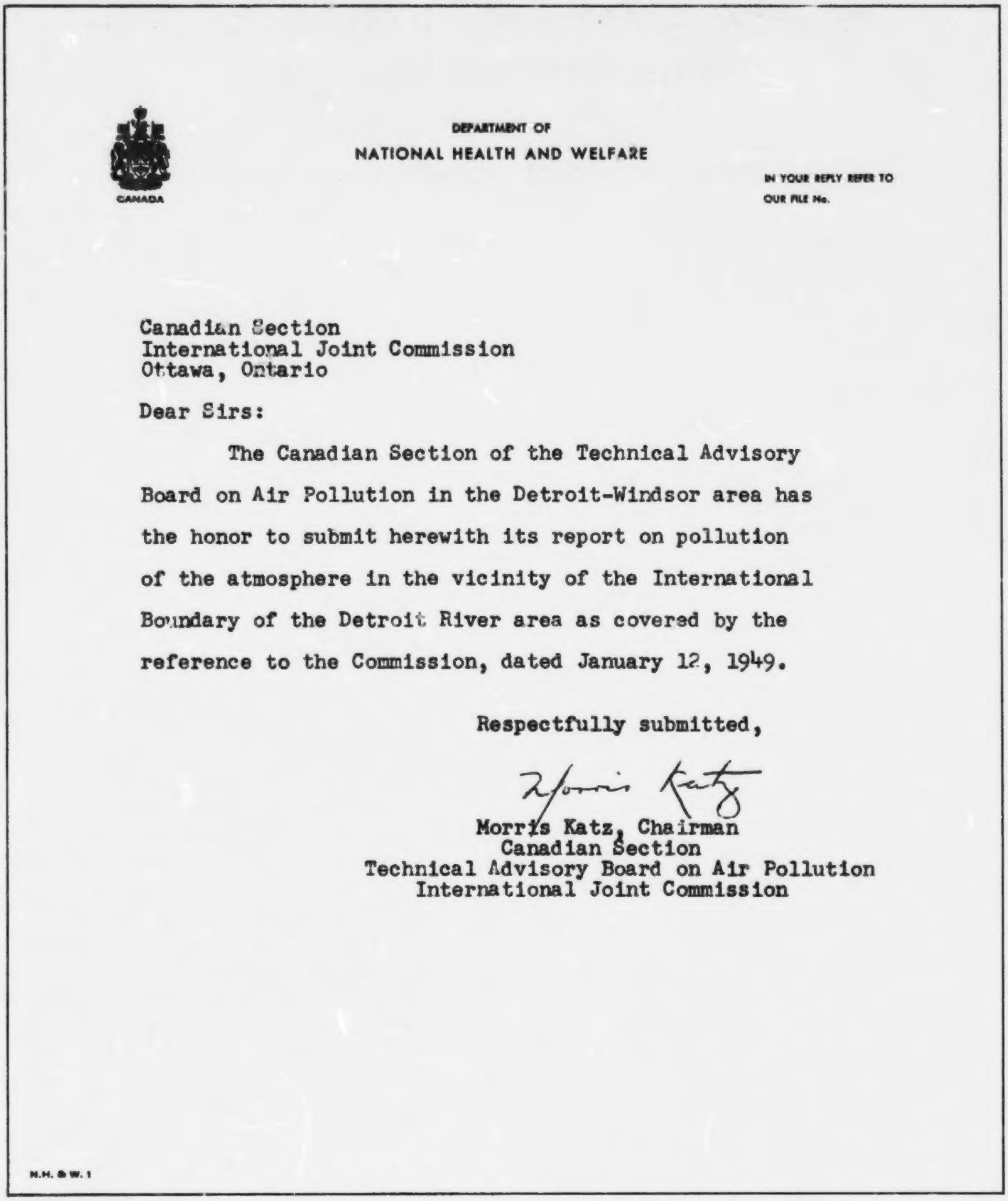
United States Section
International Joint Commission
Washington 25, D.C.

Dear Sirs:

The United States Section of the Technical Advisory Board on Air Pollution in the Detroit-Windsor area has the honor to submit herewith its report on pollution of the atmosphere in the vicinity of the International Boundary of the Detroit River area as covered by the reference to the Commission, dated January 12, 1949.

Respectfully submitted,

Arthur C. Stern
Chairman, United States Section
Technical Advisory Board on Air Pollution
International Joint Commission



CANADA

DEPARTMENT OF
NATIONAL HEALTH AND WELFARE

IN YOUR REPLY REFER TO
OUR FILE No.

Canadian Section
International Joint Commission
Ottawa, Ontario

Dear Sirs:

The Canadian Section of the Technical Advisory Board on Air Pollution in the Detroit-Windsor area has the honor to submit herewith its report on pollution of the atmosphere in the vicinity of the International Boundary of the Detroit River area as covered by the reference to the Commission, dated January 12, 1949.

Respectfully submitted,

Morris Katz

Morris Katz, Chairman
Canadian Section
Technical Advisory Board on Air Pollution
International Joint Commission

N.H. & W. 1

TECHNICAL ADVISORY BOARD ON AIR POLLUTION IN THE DETROIT-WINDSOR AREA

to the

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Chapter I

SUMMARY OF FINDINGS AND RECOMMENDATIONS

INTRODUCTION

The investigation of atmospheric pollution in the International Detroit River area has been conducted by the Technical Advisory Board over the period July 1949 to December 1957, under the terms of the Detroit River Air Pollution Reference of January 12, 1949. The Reference is as follows:

United States Section
International Joint Commission
Washington 25, D. C.

Sirs:

I have the honor to inform you that representations have been made to the Governments of the United States and Canada to the effect that the air in the vicinity of the cities of Detroit and Windsor on both sides of the international boundary in the area of the Detroit River, is being polluted by the discharge of smoke, soot and fly ash, in quantities sufficient to be detrimental to the citizens of both countries in this area. It has further been represented to the two Governments that vessels passing through the Detroit River are a source of this pollution. Pursuant to the Provisions of Article IX of the Boundary Waters Treaty, signed January 11th, 1909, the two Governments have agreed to a joint reference of this matter to the International Joint Commission. The Commission is requested to enquire into, and to report to the two Governments upon the following questions:

1. Is the air over, and in the vicinity of, the cities of Detroit and Windsor, on either side of the international boundary, being polluted by smoke, soot, fly ash or other impurities, in quantities detrimental to the public health, safety or general welfare of the citizens, or to property interests on either side of the international boundary line?

2. If the foregoing question, or any part thereof, is answered in the affirmative, to what extent are vessels plying the waters of the Detroit River, or any of them contributing to this pollution; what other major factors are responsible and to what extent?

3. If the Commission should find that vessels plying the waters of the Detroit River, or any of them, are responsible for air pollution to an extent detrimental to the public health, safety or general welfare of the citizens, or to the property interests on either side of the international boundary line,

   (a) what preventative or remedial measures would, in its judgment, be most practical from the economic, sanitary and other points of view?

(b) what would be the probable cost of such measures?

(c) by whom should cost be borne?

For the purpose of assisting the Commission in making the investigations and recommendations provided for in this reference, the two Governments, upon request, will make available to the Commission the services of engineers and other specially qualified personnel of their respective Governments, and such information and technical data as may have been acquired by such Governments or as may be acquired by them during the course of the investigation.

The Commission should submit its report and recommendations to the two Governments as soon as practicable.

Very truly yours,

(Signed) Robert A. Lovett
Acting Secretary of State

An identical reference was simultaneously received by the Canadian Section of the International Joint Commission from the Department of External Affairs of Canada.

Comprehensive studies have been made of many aspects of the pollution problem in field and laboratory work and relevant information has also been obtained from investigators in other agencies in Canada and the United States. These studies have dealt with:

1. The nature, composition and concentration of contaminants in the atmosphere from major sources involving combustion of fuels, industrial processes and others.

2. The determination of the influence of meteorological factors on the dispersion and diffusion of atmospheric contaminants.

3. The transboundary transport of air pollutants.

4. The effects of pollution on public health, vegetation, visibility, safety and economy.

5. The extent of pollution by smoke from vessels plying the Detroit River and the investigation of control and remedial measures necessary to abate this pollution.

The Detroit River area under reference includes the principal cities of Detroit and Windsor, and a considerable number of smaller municipalities located along the river. The region contains a population of about three and one-half million, largely on the United States side, and is one of the great industrial areas of North America. The Detroit River carries an enormous volume of Great Lakes vessel traffic that involves total vessel passages of about 28,000 and transport of over 100 million short tons of cargo, principally of iron ore, coal, limestone, and grain in a normal navigation season. Waste products discharged to the atmosphere from industrial and domestic activities, traffic and transportation consist of smoke, fly ash, miscellaneous coarse and fine particulate matter, sulfur dioxide, aldehydes, oxides of nitrogen, and other vapor and gaseous contaminants. Total domestic and industrial consumption of solid fuels, formerly estimated at about 15 to 16 million tons annually, has decreased to 12.4 million tons. However, total consumption of natural gas has increased to 3.8 million tons and of fuel oil to 2.9 million tons.

Early consideration was given to the problem of excessive pollution of the atmosphere by smoke from vessels plying the Detroit River. A voluntary control program was inaugurated in cooperation with the air pollution control departments of the cities of Detroit and Windsor, other municipalities, the Lake Carriers' and Dominion Marine Associations, and some affiliated organizations. In 1952 and succeeding years, with the approval of the International Joint Commission, "Smoke Emission Objectives" were established by the Technical Advisory Board to set desired limits on the emission of smoke for various classes of vessels depending upon the type of combustion equipment installed. These objectives have been modified and more restrictive standards have been established from year to year with continued improvement in smoke emission performance and abatement of pollution. A feature of this voluntary control program has been the distribution of comprehensive information on vessel smoke performance to individual owners and operators through correspondence and annual reports and the use of radiotelephone for communication with vessel captains.

The Technical Advisory Board has reached certain conclusions on the findings from this investigation and offers recommendations to the Commission for remedial measures, the probable cost of such measures and allocation of responsibility for such cost. The findings are given in some detail in Chapters II through XII. A summary is presented herewith.

FINDINGS

1. The atmosphere under reference is being polluted on both sides of the boundary to an extent which is detrimental to the communities along the Detroit River. In many places there are relatively high levels of dustfall, suspended particulate matter and sulfur dioxide. The concentrations are influenced by variable meteorological factors and show both diurnal and seasonal effects.

2. There is a transfer of pollution from each side of the boundary to the other, the most serious effect involving the flow of pollution from the River Rouge-Zug Island area of the United States to the Canadian side of the Detroit River.

3. Vessels plying the waters of the Detroit River contribute seriously to pollution in the area, particularly for short periods of time over small areas, but other major sources involving industrial, domestic and land transportation activities contribute to a much greater extent when pollution levels over the entire study area are considered. Although the voluntary vessel smoke control program has resulted in a very great improvement of smoke conditions due to vessels on the Detroit River, the excessive emission from about 25 percent of the vessels, nearly all in the hand-fired, coal-burning class, is still a source of detrimental pollution.

Because of the expected increase in marine activity in the Detroit River due to opening of the St. Lawrence Seaway and other factors, pollution from vessels could become of greater concern in the future than it is at present. Also, because of the increasing size of the Detroit-Windsor metropolitan area and the attending expanding industrial, commercial, domestic and transportation activities, pollution emissions are increasing. Unless action is taken and/or continued to control pollution emissions, pollution levels in the area will most certainly be higher in the future than they are today.

4. The city of Detroit has a vigorous program of substantial size for control of air pollution. The city of Windsor has a modest sized but energetic program. Other cities and recently Wayne County have taken some action to control pollution. No State control program is active, but Provincial legislation has been enacted. No agency has yet been successful in bringing about control of smoke from vessels in transit in the Detroit River, beyond the voluntary control program described above. It has not been established that the legal and administrative mechanisms available to State, Provincial, County and City agencies are adequate to make an effective vessel smoke control program possible.

In the United States, the Federal Government has jurisdiction over all U.S. vessels regardless of their location and over ships of all nations when they are in U.S. waters. The same is true in the case of Canada. However, neither Government has adopted legislation regulating smoke from vessels in the Detroit River.

5. Injury to vegetation has been noted on both sides of the International Boundary in proximity to some land based sources of local contamination.

6. The possible effects of air pollution on health were investigated in a two-year pilot study. It was found that the monthly rate of sickness in all areas studied followed a similar chronological pattern, although at differing levels. Two areas in Detroit showed a pattern of sickness rates indicating that rates in the high pollution area were generally at a level above those in the low pollution area. In the other groups of Detroit and in those of Windsor, the results were inconclusive. Clearly, the elucidation of the relationship between atmospheric contamination and the health status and sickness experience of

exposed population requires further study.

7. The pollution reduces visibility and solar illumination. There is also an adverse effect on property through reactions with gaseous pollutants and deposition of particulate contaminants.

8. Remedial measures are available for the control of atmospheric pollution from vessels. It is estimated that approximately 250 hand-fired vessels would have to be converted to either stoker or oil firing to meet reasonable smoke emission standards. This would cost approximately $50,000 for a four-furnace vessel converted to underfeed stoking, provided the presently installed boilers are not replaced. Conversion to oil firing for a four-furnace vessel would entail a cost of $80,000 to $90,000, approximately. For a six-furnace vessel, the installation of underfeed stokers would cost approximately $95,000 whereas the costs of conversion to oil firing would be about $100,000. In individual cases where new boilers are installed at the same time, total costs per vessel may reach $270,000 or more. At an average cost of about $75,000 per vessel, the above conversion program would entail a total expenditure of about $19,000,000 for 250 vessels.

RECOMMENDATIONS

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

1. The Governments of Canada and the United States adopt a code prescribing limitations on the emission of air pollutants from vessels in the Detroit River and standards for their measurement as follows:

a. For all vessels, except hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less:

No smoke, the shade or appearance of which is equal to or darker than No. 2 of the Ringelmann Chart shall be emitted, except that smoke the shade or appearance of which is equal to but not darker than No. 2 of the Ringelmann Chart for a period or periods aggregating not more than 4 minutes in any 30 minutes shall be permitted;

b. For hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less:

No smoke, the shade or appearance of which is equal to or darker than No. 3 of the Ringelmann Chart shall be emitted, except that smoke, the shade or appearance of which is equal to but not darker than No. 3 of the Ringelmann Chart for a period or periods aggregating not more than 9 minutes in any 30 minutes shall be permitted;

c. For the purpose of grading the shade or appearance of smoke, the Ringelmann Chart as published and used by the U. S. Bureau of Mines, shall be the standard, but the use of any other chart or device having shades equivalent to those of the Ringelmann Chart shall be authorized.

2. This code be applicable to vessels both in transit and at dockside, except where there is local legislation for control of air pollution under which effective action may be taken with regard to vessels polluting the atmosphere.

3. Two years after the official opening of the St. Lawrence Seaway or at such later time as the two Governments shall determine that such action would be in the best interests of Canada and the United States, the code be amended by deleting therefrom the exception in favor of hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less.

4. The Governments of Canada and the United States by procedure appropriate in each country take action to insure compliance with the code.

5. The Governments of Canada and the United States, in consultation with Provincial, State, county, township and city governments, develop legal and administrative procedures for dealing with noncompliance with and revision of the code; develop appropriate methods for establishing proof of such noncompliance; study and resolve related questions such as the definition of the jurisdictions of courts concerned with the enforcement of the code, and of extenuating circumstances under which deviations from the code may be permitted.

6. The Technical Advisory Board on Air Pollution, as presently constituted for the Detroit-Windsor Reference of January 12, 1949,

be relieved of its duties.

7. A Board of Control on Air Pollution be established as soon as possible to serve in an advisory capacity to the Commission in regard to the smoke emission from vessels plying the Detroit River. It would be the duty of this Board to keep the International Joint Commission advised of progress made in the control of air pollution from such vessels; maintain effective liaison with Provincial, State, county, city and other jurisdictions in order to provide such mutual assistance and cooperation as may be appropriate; and on behalf of the Commission, until the adoption and implementation of the code, conduct a continuing program of observation and control of vessel smoke emission on a voluntary basis in cooperation with vessel owners and operators and local authorities.

8. The voluntary control program referred to in recommendation 7 have the following smoke emission objectives for the various classes of fuel-burning equipment on vessels:

MAXIMUM NUMBER OF MINUTES OF SMOKE EMISSION IN ANY 30-MINUTE PERIOD

Fuel-burning equipment	Minutes at Ringelmann Number				
	1	2	3	4	5
Objective 1 Oil-fired, under-feed-stoker-fired and diesel engines	30	4	0	0	0
Objective 2 Spreader-stoker-fired	30	30	3	0	0
Objective 3 Hand-fired	30	30	9	0	0

9. Appropriate jurisdictions fronting the Detroit River be encouraged to adopt the limitations of emission of smoke and air pollutants as adopted by the Governments of Canada and the United States, so that vessels in transit and at dockside will be subject to uniform codes.

10. The costs incurred for vessels to meet these codes or the voluntary smoke emission objectives be borne solely by the owners of such vessels.

Chapter II

LEGISLATION AND REGULATION PERTAINING TO AIR POLLUTION IN THE DETROIT RIVER AREA

UNITED STATES

FEDERAL

Section 8, Article I, of the Constitution permits Congress "To regulate commerce with foreign nations and among the several states . . . " In Section 2, Article III, of the Constitution, the nature of cases subject to the judicial power of the United States is set forth. It is stated "The judicial power shall extend to all cases in law and equity arising under this Constitution, the laws of the United States and the treaties made, or which shall be made under their authority; . . . to all cases of admiralty and maritime jurisdiction . . . "

American flag vessels on the Detroit River have been held subject to the admiralty jurisdiction of the United States, and therefore, Congress could validly prescribe for the punishment of crimes committed aboard such vessels regardless of whether the vessel was in American or Canadian waters at the moment the crime was committed. (United States vs. Rodgers 150 U.S. 249 (1893)).

The Federal Government may also provide that violation of a State law be construed as a violation of a Federal law (United States vs. Howard 88 S. Ct. 303 (1957); Gauley Mountain Coal Co. vs. Director of U.S. B. Mines, 224 F. 2d 887 (1955)). Thus, if a State air pollution control law were enacted and if the Federal Government made violation of that law a violation of Federal law, prosecution for violation of the State law could be undertaken either in Federal courts, based on evidence obtained by the State agency, or in the State courts (United States vs. Howard 77 S. Ct. 303, 305).

At this time, there is no Federal law providing specifically for the control of atmospheric pollution. Public Law 159, of the 84th Congress, approved by the President on July 14, 1955, authorizes a Federal program of research and technical assistance relative to air pollution. The law states as the policy of Congress that legal control of air pollution is a responsibility of state and local governments.

STATE OF MICHIGAN

States have the authority to enact laws providing for the regulation of human behavior, the conduct of business, the use of property and so on, with reference to the maintenance of public order and the protection of the public health, safety and morals. Under these broad but not unlimited police powers, a program can be provided which will bring about control of air pollution within the boundaries of the state. In behalf of their residents, states may also utilize the common law relating to nuisances in providing for control of air pollution nuisances. Further, states have the power to declare certain acts or situations, including emission of air polluting materials, to be nuisances.

At present, there is no State legislation in Michigan concerned specifically with air pollution control. However, the Michigan State Department of Health has certain authority which may be applicable to specific air pollution situations. These include the following powers:

1. To study vital statistics and make use of health records accumulated from these statistics.

2. To make investigations and inquiries respecting the cause of disease and "the effects

of locality, employments, conditions, ingesta, habits and circumstances on the health of the people."

3. To advise local health officials "in regard to the location, drainage, water supply, disposal of excreta, heating, and ventilation of any public building or institution." (a)

In addition, the original statutory authority of the State Board of Health made it a legal duty and responsibility for all officers of the State and the "president or agent of any company chartered, organized, or transacting business under the laws of this State, so far as is practicable, to furnish to the State Board of Health any information bearing upon public health which may be requested by said board . . . " The general investigatory function of the Board of Health was made more precise by 1909 legislation and a 1912 attorney general's opinion that authorized and upheld the power of the State Board of Health to order investigations of occupational sickness and disease. (b)

The State has enacted enabling legislation in such fields as housing, zoning, and fuel oil usage which may be adopted by local option. However, no such action has been taken with regard to air pollution.

There have been a number of efforts to secure adoption of air pollution control legislation in the Michigan State Legislature. Although several bills have been introduced, none had met with the approval of the legislature as of September 1958. In 1955, the Michigan State Health Department prepared a draft bill concerning control of air pollution. This measure would not have assigned major control powers to the State but would have followed the pattern set in the fields of housing, fuel oil control, building regulation, and zoning mentioned above. During the 1956 legislative session, two separate air pollution control bills were introduced. One (House Bill No. 48) was patterned after those then in existence in the States of Oregon and New Jersey. The other (House Bill No. 87) placed principal responsibility for the control of air pollution in the State Health Department and also provided for an air pollution hearing board.

The Division of Occupational Health of the Michigan Department of Health has carried on limited activities in the field of air pollution control under the general authority vested in the Health Department. This Division has worked with local agencies by providing them with technical information to assist them in obtaining abatement of air pollution problems. Sampling, testing, and engineering recommendations concerning means for controlling pollution have been provided. Public complaints directed to the State are investigated and when warranted, efforts are made to secure abatement of unsatisfactory conditions. Educational work to promote air pollution abatement actions is rather extensive. No separate staff or budget is maintained for air pollution work. Occupational health personnel do the air pollution work along with their regular industrial hygiene work. There has been no significant activity by the State with regard to control of air pollution from vessels plying the Detroit River.

WAYNE, MACOMB AND OAKLAND COUNTIES

The basic legislation for the formation of county health districts was Public Act No. 130 of the Michigan Legislature of 1917. This Act authorized the formation of health districts of contiguous townships and villages and the appointment of boards of health. It also authorized the exercise of all powers granted by the general law of the State to boards of health. This authority included the promulgation of regulations respecting nuisances and other matters pertaining to public health which were not repugnant to the general laws of the State. This Act was repealed by Public Act No. 306 by the 1927 Michigan State Legislature which provides for the establishment of county health departments having authority to administer all health laws and to control communicable disease, with the advice and direction of the State Department of Health. This Act further provides for the jurisdiction of such health departments throughout the counties except in cities having organized health departments with full-time health officers. Such cities may elect to join their health departments with those of the counties. The Michigan State Legislature of 1941 passed Public Act No. 198, which amended Public Act No. 306 to authorize county boards of supervisors to establish county and district boards of health.

(a) Michigan Statutes Annotated, Chapter 14.4. The original assignment to the Board of Health was contained in C.L. 1915, par. 4988-4998, and was enacted by the legislature in Act No. 81, Public Acts of Michigan of 1873.

(b) Act No. 293, Public Acts of Michigan of 1909 and Opinions of the Attorney General, 1912, p. 152.

Of the three counties lying partially or completely within the area of study, air pollution regulations have been promulgated only by the Wayne County Board of Health. These regulations, adopted August 24, 1955, were issued on the basis of the broad authority given to county health departments to make regulations and by-laws respecting nuisances.

The air pollution regulation of Wayne County assigns to the County Board of Health the following powers and duties:

1. The Board of Health shall adopt and amend rules and regulating or prohibiting the emission into the open air from any source, whether fixed or movable, or any harmful or objectionable substance included but not limited to smoke, soot, fly ash, dust, fumes, gas, vapors and odors and the installation, construction or alteration of equipment given forth such emissions into the open air.

2. The Board may fix fees for filing of any documents, for the issuance of permits and for the examination of plans.

3. Develop a program for the prevention and control of all sources of pollution of the air in the county.

4. Advise, consult and cooperate with other agencies of the State and political subdivisions.

5. Collect and disseminate information relating to air pollution, its prevention and control.

6. Encourage voluntary cooperation by the people, municipalities, industries and others in restoring and preserving the purity of air within the county.

7. For the purpose of investigating conditions relating to air pollution, the members of the Board or their duly authorized representatives shall have the authority to enter, when necessary, upon any private or public property.

The air pollution control activity of the Wayne County Department of Health is just getting under way. A staff of about four persons is presently envisioned. It is anticipated that the basic contribution will be encouragement and assistance to cities, villages, and townships in their own air pollution control activities. The Board of Health is expected to implement the basic regulations with more detailed rules. The county probably will not assume actual enforcement responsibility unless the source of pollution is located in an area where there is no city, village, or township control agency. No standards relating to smoke emission or other pollution emissions have yet been promulgated. No action has been taken regarding smoke emitted by vessels plying the Detroit River, but no legal reason is seen which would prevent such action within the Wayne County jurisdictional area.

CITIES, VILLAGES, AND TOWNSHIPS

Introduction

Cities, villages, and townships in Michigan have been given no specific authority by State law or constitution to enact air pollution or smoke control legislation. However, there is no restriction on their doing so. Such local legislation is enacted under the general police and nuisance abatement powers embodied in their charters. The only exceptions apply to the fourth-class cities which are charted under special State legislation, but in these cases also, no specific mention is made of air pollution control authority. Michigan is a home rule State and permits, by its constitution, great freedom to local governments to establish in their charters whatever reasonable organization and functions the local governments may desire. Consequently, initiative and authority in establishing air pollution control legislation rest with local jurisdictions.

Detroit

The only major municipal air pollution control program in the U.S. portion of the study area is carried on by the City of Detroit. The program is comprehensive and includes most of the functions found in large air pollution control programs in the United States. The program is administered by the Bureau of Smoke Inspection and Abatement of the Department of Buildings and Safety Engineering.

The smoke abatement code entitled "An Ordinance Regulating Smoke and Air Pollution in the City of Detroit" is the basis of operation of the Detroit air pollution control program. (Ordinance 167-E, as amended by Ordinance 793-E, effective September 17, 1953, and supplemented by Ordinance 77-F, effective December 1, 1955.) Briefly, it provides the following:

1. Defines the terms used in the ordinance.

2. Declares emission of certain dense

smoke and other pollutants to be a nuisance and make it unlawful to permit such pollution emissions.

3. Prohibits open fires except with special approval.

4. Limits emission of air-borne solids (fly ash and other material) from fuel-burning devices and other process equipment.

5. Prohibits use of high volatile coal (in excess of 23 percent volatile) in hand-fired and intermittently fed surface-burning equipment, except under certain conditions.

6. Requires reports of purchases of combustion equipment.

7. Requires fuel purchasers to inform fuel dealers of the type of burning device in which fuel is to be used; requires fuel dealers to keep a record of such information; and prohibits sale of fuel for use in a device for which it is illegal.

8. Requires approval of plans for fuel and refuse burning plants prior to installation or alteration except in small residential buildings.

9. Requires annual inspections and certificates of operation for fuel- and refuse-burning plants, except in small residential buildings.

10. Authorizes sealing of equipment after three violations of the ordinance within a 12-month period and after a hearing, and of equipment found unsatisfactory upon annual inspection.

11. Requires proper combustion devices on railroad locomotives and air pollution control measures in locomotive engine houses.

12. Establishes an air pollution advisory board.

13. Regulates construction of refuse-burning devices.

14. Authorizes promulgation of rules, regulations, and standards for stokers and fuel-burning equipment and devices for preventing pollution of the atmosphere and for any other special requirements that may arise in conjunction with the burning of fuel or pollution of the air.

The Detroit Bureau of Smoke Inspection and Abatement is staffed by about 28 people and in 1956 had an operating budget of almost $200,000. During 1956, in addition to other activities, the Bureau arranged for correction of nearly 1,900 unsatisfactory air pollution situations, approved nearly 2,000 installations of equipment, made over 4,700 annual inspections, and investigated over 2,200 air pollution complaints. Hearings were held concerning 75 cases and 42 court cases were instituted. A program of public education is carried on through radio, television and personal appearances as well as through newspapers and other published material.

The Detroit Department of Health, Bureau of Industrial Hygiene conducts a supplemental program directed principally toward appraisal of atmospheric quality and determination of possible health influences of atmospheric pollution. Two to four people are engaged in this work. Expenditures are estimated at $15,000 to $20,000 per year.

The City of Detroit has taken action to control air pollution emissions from some vessels docking within the jurisdictional area of the city. As a result of such action taken by the cities of Detroit and Windsor, owners of ferry boats which dock in the city have taken steps to control pollution and only one ferry remains which does not have a satisfactory smoke emission performance. Action to obtain corrections on this vessel is proceeding. Very recently actions have been taken to control smoke from a number of vessels plying the Detroit River within the corporate limits of Detroit. These actions are still pending.

Other United States Cities and Villages

There are 11 other cities and villages among the more than 80 cities, villages, and townships in the study area which carry on activities recognized specifically as air pollution control. In other cities, villages and townships, health departments undertake limited activity to abate pollution nuisances. Generally, building code provisions concerning chimneys and combustion devices provide a limited degree of air pollution control.

The 11 jurisdictions with specific air pollution control activities include Dearborn, Ferndale, Grosse Point Farms, Grosse Point Park, Hamtramck, Highland Park, Livonia, River

Rouge, Trenton, Wyandotte, and Royal Oak. All have air pollution control ordinances except Ferndale, whose air pollution standards are embodied in the zoning law. The programs are administered by various agencies including health, building, public works and fire departments, and city engineering and inspection departments. Generally, the part-time services of one person are available for air pollution control work, although a few agencies have slightly more personnel time available.

Typical Pollution Emission Standards

The City of Detroit air pollution ordinance prohibits emission of smoke equal to or darker than that prescribed as No. 2 on the Ringelmann Chart except that smoke equal to but not darker than No. 2 may be emitted for a period or periods aggregating 4 minutes in any 30 minutes, and smoke equal to but not darker than No. 3 Ringelmann may be emitted for a period or periods aggregating 3 minutes in any 15 minutes when building a new fire. The use of an Umbrascope or Ringelmann Chart is permitted in determining smoke density. Emission of air-borne solids from combustion and process equipment is limited to 0.3 grains per cubic foot of gas, determined at 500 degrees Fahrenheit and with less than 50 percent excess air. Included also is a general prohibition of pollution emissions which are detrimental to any person or which endanger the health, comfort, or safety of any person, or which may cause injury or damage to property or business.

The Dearborn air pollution ordinance contains the same smoke emission standards as the Detroit ordinance but the limits are not applicable to residences having less than four dwelling units nor to railroad engines or roundhouses. Special, but similar standards are given for railroad engines. Use of the Ringelmann Chart or the Umbrascope is permitted in determining smoke density. Emission of air-borne solids from combustion or processing equipment is limited to 0.2 grains per cubic foot of carrying medium corrected to 500 degrees Fahrenheit and 50 percent excess air except for incinerators with a rated capacity of 60 pounds per hour per square foot of grate area or less. These smaller incinerators are limited to 0.3 grains per cubic foot of carrying medium under the same conditions. A general provision limiting nuisance type pollution emissions similar to that in the Detroit ordinance is included.

The Wyandotte ordinance has the same smoke emission standards as the Detroit ordinance and includes a prohibition of emissions which may be a nuisance or which may be detrimental to comfort, health, safety, business or property. The provisions regulating smoke and other pollution emissions do not apply to dwellings heated by a separate, self-contained heating plant. Emission of dust, soot, or fly ash from fuel-burning or dust-separating equipment is limited to 0.85 pounds per 1000 pounds of gases, adjusted to 12 percent carbon dioxide, except that dust, soot, or fly ash not exceeding 15 percent of the total entering any dust-separating equipment is permitted to be discharged.

The Hamtramck ordinance has the same smoke emission standards as the Detroit ordinance, except that railroad locomotives are permitted to emit smoke equal to but not darker than No. 3 Ringelmann for a period of 20 minutes in one hour, once every 24 hours when a new fire is being built or for a period or periods aggregating six minutes in any one hour but not exceeding two minutes of continuous emission of No. 3 smoke. This ordinance sets no specific limits on emission of air-borne solid particles but does have a general type provision which prohibits emission of any pollutant which would cause injury, detriment, or nuisance or endanger the comfort, health, or safety, or cause or have a tendency to cause injury or damage to business or property. The Ringelmann Chart or the Umbrascope may be used in determining smoke density.

ZONING LAWS OF LOCAL GOVERNMENTS

A large majority of the communities in the study area have zoning laws. Although operation of zoning programs does not directly regulate air pollution, the programs do serve to separate likely major sources of pollution from residential, recreational, institutional, and human care occupancies. Thus, those areas most likely to be adversely affected by pollution are not subject to the relatively high pollution levels often found in close proximity to major pollution sources. However, only seven communities in the area prohibit residential land uses in industrial zones. These are Detroit, Dearborn, Livonia, Wyandotte, East Detroit, Warren and Oak Park. Of these, only Detroit, Dearborn, Warren, and Wyandotte are sufficiently industrialized for the prohibition to be meaningful. Thus, persons may ill advisedly establish residential land uses near industrial plants and perhaps be subjected to relatively high pollution levels. All zoning ordinances in the study area prohibit the use of land in all types of residential areas for any kind of industrial process. In multiple family dwelling zones, however, some business and commercial uses, a few of which create minor local pollution problems, are permitted in most ordinances.

In some respects the Detroit River may be looked upon as an area over which local authorities have no zoning control. It is obviously impossible to prohibit vessels from using the river. Yet some vessels are sources of substantial amounts of pollution and in passing through the river, may discharge pollutants in close proximity to a number of residential, commercial and recreational areas. Zoning programs would attempt to eliminate such a situation on land, but they cannot reasonably attempt such control with respect to the river.

NON-GOVERNMENTAL ACTIVITY

In 1946, a Metropolitan Committee on Smoke Abatement and Sanitation was developed, with Detroit officials taking the lead in the formation of a special committee of community representatives. Its beginnings developed from an area-wide concern for the problems of smoke abatement and rat control, matters that do not respect municipal boundaries. By 1948, 29 communities and the health departments of Wayne County and the State had joined the committee. The committee has no official status or formal authority and takes no action on the legislation or administrative actions of any of the member communities. It tends to act as an information clearinghouse with the hope that an exchange of problems and ideas may produce a certain area-wide uniformity of program and procedure.

CANADA

FEDERAL

The Federal Government in Canada, which derives its authority from the British North America Act, exercises all powers not specifically delegated to the provinces.

The control of air pollution is a Provincial function except for control of the emission of air contaminants from vessels plying navigable waters and from equipment used by railways engaged in interprovincial commerce.

Through the Canada Shipping Act, the Federal Government exercises control of vessels on all navigable waters within its jurisdiction. The Act authorizes the Governor in Council to make regulations governing the emission of smoke from vessels in Canadian waters including the Canadian portion of the Detroit River without conflict with the powers of the Provinces or local municipalities. To date, no such orders have been issued.

The Railway Act, a Federal measure, confers on the Board of Transport Commissioners for Canada, control of the activities of the railway systems crossing Provincial boundaries. Regulations have been issued by this board governing the emission of smoke from locomotives and other railway installations.

The Department of National Health and Welfare has assumed certain responsibilities in connection with air pollution and has established advisory and other services.

PROVINCE OF ONTARIO

The control of air pollution is the responsibility of the Provinces, except in the case of vessels and railways as cited above. Until recently, The Ontario Municipal Act contained enabling legislation whereby municipalities could pass by-laws to control the emission of smoke and other products of combustion within their boundaries. Recently, the sections of The Municipal Act dealing with air pollution were repealed and The Air Pollution Control Act 1958 was passed. This Act became effective on May 21, 1958. It gives broad powers to municipalities to prohibit or regulate emission of air contaminants from any source. An Air Pollution Control Branch has been established in the Ontario Department of Health to furnish advice in the field of air pollution, to assist municipal officials in the preparation of air pollution control by-laws in development of air pollution control programs, and in training of local staffs for this purpose. Authorization is given to investigate or make arrangements for investigation of air pollution problems.

The Ontario Public Health Act deals with a variety of public health problems. The provisions of the Act relative to air pollution problems are not enforceable unless it can be shown that the pollution is injurious or dangerous to health. In practice, medical officers of health have not undertaken air pollution control work under the terms of the Act

One further legal device available to the Province may be mentioned. Under the Sulphur Fume Damage Arbitration Act, an abritrator, acting under the Ontario Department of Mines, may appraise damages and assess penalties in such cases as injury to agricultural and forest species by sulfur fumes from smelting or refining of nickel, copper, or iron ores.

CITY OF WINDSOR

By-Law No. 799 of December 1949 provides the legal basis for smoke abatement activities in Windsor. The salient features of this by-law are as follows:

1. Prohibits the emission of smoke the shade or appearance of which is equal to or denser than No. 2 of the Ringelmann Smoke Chart except for a period or periods aggregating four minutes in any one half hour and except for a period or periods of not more than three minutes in any quarter hour, when smoke equal to or denser than No. 3 of the Ringelmann Chart is permitted, when building a new fire.

2. Prohibits emission of fly ash in excess of 0.85 pounds per 1000 pounds of gases, adjusted to 12 percent carbon dioxide except that not more than 15 percent of the fly ash entering dust separating equipment may be discharged.

3. Requires approved dust-separating equipment on pulverized fuel and spreader stoker-fired units.

4. Requires smoke indicators in most larger plants.

5. Requires installation and operating permits for fuel burning devices including requirement to have plans and specifications approved before work is done.

6. Provides for requirement of increased chimney heights or other measures to abate certain nuisances.

7. Establishes an advisory, appeal, and regulating board.

8. Requires the reporting of sales of fuel burning equipment.

9. Exempts all dwellings which are heated by a separate heating plant from all provisions of the by-law.

The by-law is administered by one inspector in charge of the Air Pollution Control Department, assisted by a clerk. The work is largely concerned with smoke and fly ash from combustion of fuel and only to a small extent with other pollution problems. The inspector seeks out violations of the smoke abatement law and through cooperation with responsible parties, arranges for abatement of unsatisfactory conditions. In a few cases legal action is taken to require compliance with the by-law. In cooperation with the city's heating inspectors, checks are made to insure that new installations and repairs are made in such a manner that air pollution problems are avoided. The City has successfully prosecuted actions in court with regard to violation of the smoke abatement by-law by vessels tied up at city docks.

OTHER CANADIAN TOWNS

By-Law No. 783 provides the legal basis for dense smoke protection in the town of Amherstburg. It does not specify an administrative procedure and is much less restrictive and not as comprehensive as the Windsor by-law. The by-law does not define permissible limits of smoke emission.

There is no air pollution control legislation in effect in the towns of Riverside, LaSalle, Sandwich East, Sandwich West, Tecumseh, or Harrow. Most of these towns are separately incorporated, but Sandwich East and Sandwich West, which adjoin Windsor, are under Essex County administration. Instances of pollution originating in some of these communities and affecting the immediately adjacent city of Windsor have emphasized the necessity for regulations adequate for the circumstances. The communities have indicated their desire to cooperate in the solution of common problems relating to air pollution. They are interested in the interurban aspects of the problem, and in uniform regulations aimed at improving conditions along the Detroit River.

ESSEX COUNTY

Essex County is largely rural. However, sizeable communities of as many as ten thousand people are immediately adjacent to Windsor. Some areas of the communities are in process of industrialization, and air pollution will doubtless become a problem of increasing significance. No formal air pollution control program is being carried on by the county.

INTERNATIONAL JOINT COMMISSION

The International Joint Commission has authority to examine and report on any matter referred to it by the Governments of the United States and Canada. The two countries agreed to refer problems of international concern to the Commission under terms of Article IX of the Boundary Waters Treaty of 1909. The Commission's reports to the Governments are not to be regarded as decisions nor may they have the character of an arbitral award under the terms of this article. However, in Article X of the treaty, provision is made for the two Governments to refer matters to the Commission for decision. The Detroit River area air pollution reference was made to the Commission under terms of Article IX, and therefore, the Commission's report on the matter will not be regarded as a decision. The actions recommended by the Commission may be taken by the two Governments, not the Commission.

A previous air pollution problem of concern to both countries was referred to the International Joint Commission. This was the well known case involving pollution from the smelter at Trail, British Columbia, referred to the Commission in 1928.

Article IX of the "Treaty Between the United States and Great Britain Relating to Boundary Waters, and Questions Arising Between the United States and Canada" of 1909 is as follows:

> "The High Contracting Parties further agree that any other questions or matters of difference arising between them involving the rights, obligations, or interests of either in relation to the other or to the inhabitants of the other, along the common frontier between the United States and the Dominion of Canada, shall be referred from time to time to the International Joint Commission for examination and report, whenever either the Government of the United States or the Government of the Dominion of Canada shall request that such questions or matters of difference be so referred.
>
> The International Joint Commission is authorized in each case so referred to examine into and report upon the facts and circumstances of the particular questions and matters referred, together with such conclusions and recommendations as may be appropriate, subject, however, to any restrictions or exceptions which may be imposed with respect thereto by the terms of the reference.
>
> Such reports of the Commission shall not be regarded as decisions of the questions or matters so submitted either on the facts or the law, and shall in no way have the character of an arbitral award.
>
> The Commission shall make a joint report to both Governments in all cases in which all or a majority of the Commissioners agree, and in case of disagreement the minority may make a joint report to both Governments, or separate reports to their respective Governments.
>
> In case the Commission is evenly divided upon any question or matter referred to it for report, separate reports shall be made by the Commissioners on each side to their own Government."

Chapter III

ORGANIZATION OF THE INVESTIGATION

TECHNICAL ADVISORY BOARD

The International Joint Commission, in April 1949, appointed the Technical Advisory Board on Air Pollution, composed of three experts from the United States and three experts from Canada, to act as technical advisors and to supervise conduct of the investigation. Membership of this Technical Advisory Board on Air Pollution was increased from six to eight in April 1954 by the addition of two medical experts.

Composition of the Board, both past and present, is as follows:

FOR THE UNITED STATES

Mr. J. F. Barkley, Consultant; formerly Chief, Fuels Utilization Branch, U. S. Bureau of Mines, Washington, D. C. (1949 to date).

Mr. L. M. Fisher, retired; then Assistant to the Chief Engineer, U. S. Public Health Service, Washington, D. C. (Chairman, 1949).

Dr. H. H. Schrenk, Director of Research, Industrial Hygiene Foundation, Mellon Institute, Pittsburgh, Pennsylvania; then Chief, Environmental Investigations Branch, Division of Industrial Hygiene, U. S. Public Health Service, Washington, D. C. (1949).

Mr. C. H. Atkins, Regional Engineer, Region III, U. S. Public Health Service, Charlottesville, Virginia; then Chief, Division of Sanitation, U.S. Public Health Service, Washington, D.C. (1950 to 1953).

Mr. G. D. Clayton, George D. Clayton & Associates, Detroit, Michigan; then Air Pollution Engineer, Division of Occupational Health, U.S. Public Health Service, Cincinnati, Ohio (Chairman, 1950 to 1954)

Mr. P. D. Haney, Black & Veatch Consulting Engineers, Kansas City, Missouri; then Chief, Survey and Investigation Branch, Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio (1953 to 1954).

Dr. C. P. Anderson, Deputy Health Commissioner, Medical Services, Department of Health, Detroit, Michigan (1954 to date).

Dr. A. T. Rossano, Jr., Chief, State & Community Services, Air Pollution Engineering Research, Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio; then Air Pollution Engineer, Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio (Chairman, 1955).

Mr. A. C. Stern, Chief, Air Pollution Engineering Research, Sanitary Engineering Center, U. S. Public Health Service, Cincinnati, Ohio (Chairman, 1955 to date).

Dr. L. C. McCabe, President, Resources Research, Inc., Washington, D. C.; formerly Chief, Fuels and Explosives Division, U. S. Bureau of Mines, Washington, D. C. (1955 to date).

FOR CANADA

Dr. M. Katz, Consultant, Atmospheric Pollution Services, Department of National Health and Welfare, Ottawa, Ontario (Chairman, 1949 to date).

Mr. J. R. Menzies, Chief, Public Health Engineering Division, Department of National Health And Welfare, Ottawa, Ontario (1949 to date).

Dr. A. E. R. Westman, Director, Department of Chemistry, Ontario Research Foundation, Toronto, Ontario (1949 to 1950).

Dr. C. M. Jephcott, Director, Air Pollution Control, Ontario Department of Health, Toronto, Ontario (1950 to date).

Dr. E. A. Watkinson, Principal Medical Officer, Environmental Health and Special Projects, Department of National Health and Welfare, Ottawa, Ontario (1954 to 1958).

Dr. T. H. Patterson, Chief, Occupational Health Division, Department of National Health and Welfare, Ottawa, Ontario (1958 to date).

Meetings of the Technical Advisory Board were held to plan the necessary studies, give technical direction to the field work, review findings, prepare periodic progress reports and make recommendations to the Commission. This work has been carried out not only with a field staff under the direct supervision of the Board but also with the assistance of Federal, State, Provincial, and municipal agencies. The Canadian and United States portions of the investigation were coordinated, utilizing similar sampling and analytical techniques insofar as possible. The first meeting of the Technical Advisory Board was in Windsor on May 12, 1949. Meetings were held frequently during the formative stages of the study but later were decreased to about three per year.

Although the Reference clearly outlines the scope of the study, the geographic area is defined only in general terms. At an early meeting of the Board the study area was, therefore, defined as extending from Peache Isle at the north end of the Detroit River to the south end of Grosse Ile at the southern part of the river and to a distance of 15 miles inland on each side of the river.

On the Canadian side, field headquarters and a laboratory were established at 108 MacDougall Avenue, Windsor, Ontario. Headquarters on the United States side were located in the Majestic Building, Detroit. In 1955 they were moved to the City of Detroit's Herman Kiefer Hospital, and in 1956 were again moved, this time to the Robert A. Taft Sanitary Engineering Center of the Public Health Service in Cincinnati, Ohio.

OBJECTIVES OF THE STUDY

After review of the Reference, the Board adopted the following objectives to provide the necessary information to the Commission:

1. Determination of the sources, nature and amounts of atmospheric contaminants resulting from the combustion of fuels and industrial processes.

2. Determination of the influence of meteorological factors on dispersion and diffusion of atmospheric contaminants.

3. Study of the extent of transboundary flow of atmospheric pollution.

4. Determination of the effect of atmospheric contaminant levels upon public health, vegetation, visibility, and economy.

5. Determination of the extent of pollution from vessels plying the waters of the Detroit River, the investigation of the control and remedial measures necessary to abate this pollution, the probable cost of such measures and by whom the cost should be borne.

FIELD AND LABORATORY STAFF

CANADA

Direct supervision of the studies on the Canadian side was assumed by Dr. Morris Katz who at that time was employed by the Defense Research Board as a research scientist. Actual work on the studies in Canada was commenced by one engineer at Windsor, Ontario, in July 1949. Steps were taken to acquire necessary sampling and laboratory equipment for environmental measurements of atmospheric contaminants. These preliminary arrangements were completed by fall of 1950. The following personnel have been engaged on the air pollution studies in the Windsor area and related projects for varying periods:

Mr. Gerald Derouin, Engineer, 1949 to 1954.

Mr. G. A. Cave, Chemist, Officer-in-Charge, Windsor Laboratory, 1950 to 1955.

Mr. M. B. Ferguson, Engineer, 1950 to 1954.

Mr. D. H. Becking, Engineer, 1951 to 1952.

Dr. Violet C. Shore, Spectroscopist, Defense Research Chemical Laboratories, Ottawa, 1952 to 1955.

Mr. A. F. W. Cole, Chemist, 1953 to 1955, Officer-in-Charge, Windsor Laboratory, 1955 to 1957.

Mr. G. E. Moore, Chemist, 1954 to 1957.

Mr. H. P. Sanderson, Chemist, 1954 to 1957.

Several technicians have been employed from time to time at the Windsor Laboratory. Among these were Messrs. Brandt, Hill, and Nidecker. During the summer months of each year since 1950, two university students have been engaged in making observations of smoke emissions from vessels plying the Detroit River.

In 1951, through the courtesy and cooperation of Mr. Andrew Thomson, O. B. E., Controller, Dominion Meteorological Services, Department of Transport, Mr. H. W. Baynton, a senior meteorologist, was assigned to the Windsor Laboratory to assume responsibilities for meteorological studies on both sides of international boundary. Mr. Baynton remained on this assignment until 1955. His duties were taken over in 1956 by Mr. R. E. Munn of the Department of Transport.

Valuable assistance in training of staff engaged in the vessel smoke program, in procurement of suitable sites for establishment of field sampling stations and in many other services has been rendered by the Chief Smoke Inspectors of the City of Windsor, formerly Mr. R. E. Nicholls and latterly Mr. S. C. Boyle.

Specialized equipment and laboratory facilities for x-ray diffraction, spectrographic and microscopic studies of the composition and character of particulate pollutants were made available by the Defense Research Chemical Laboratories of the Defense Research Board at Ottawa.

UNITED STATES

On the United States side, Mr. George D. Clayton assumed direct charge of the field work, assisted by Mr. Paul M. Giever, both of the United States Public Health Service. Air pollution measurements and other environmental studies were started in the spring of 1951.

The following persons and organizations materially assisted in the environmental, meteorological, and laboratory studies:

United States Public Health Service
Division of Occupational Health

Analytical Unit
Dohrman H. Byers, Chief
Spectrographic Unit
Robert Keenan, Chief
Statistical Unit
William Gafafer, Chief
Hugh P. Brinton

United States Weather Bureau

Scientific Services Division
Fred White
Detroit Office
W. W. Oak, Meteorologist-in-Charge

Detroit Department of Health
Bureau of Industrial Hygiene
William G. Fredrick, Director

Detroit Department of Buildings & Safety Engineering Bureau of Smoke Inspection and Abatement, J. W. Shaw, Chief Smoke Inspector, and then later Benjamin Linsky, Chief Smoke Inspector

Michigan Department of Health
Division of Occupational Health
John Soet, Director

Mr. Clayton and Mr. Giever resigned from the U. S. Public Health Service in 1955. Mr. Jean J. Schueneman, U. S. Public Health Service, Sanitary Engineering Center, Cincinnati, Ohio, carried out work for the Board from 1955 to August 1958. Since then, Dr. R. O. McCaldin of the Sanitary Engineering Center has assumed this responsibility.

The Detroit Bureau of Industrial Hygiene and the Detroit Bureau of Smoke Inspection and Abatement rendered valuable assistance in field sampling and collection of data on suspended particulate matter and sulfur dioxide. Other special services rendered by the Bureau of Smoke Inspection and Abatement included assignment of working quarters for United States technical personnel engaged in the air pollution study, compilation of data and preparation of maps of air pollution sources, study of smoke emission from vessels on the Detroit River, and servicing of high-volume air samplers.

STUDY OF VESSEL SMOKE

The Technical Advisory Board gave early consideration to the problem of excessive smoke emission from vessels plying the Detroit River. Measurements of smoke emission by the Ringelmann Chart method were commenced in July of 1949 from the Windsor side of the river. This study has been continued in each navigation season since 1949. The main responsibility for gathering of data and compilation of results has been vested in the Canadian Section of the Board. Up to 1955, the City of Detroit, Bureau of Smoke Inspection and Abatement, assigned an observer to make smoke measurements from the United States side of the river. Since 1955, this work was done by the staff employed by the United States Section of the Board.

Annual reports on the smoke performance of from 450 to 650 vessels in each season have been submitted to the International Joint Commission and distributed to Great Lake vessel owners and operators, the Dominion Marine Association, the Lake Carriers' Association, air pollution control agencies along the Detroit River and other interested parties.

At a public hearing on October 18 and 19, 1950, at Detroit, the Commission requested the cooperation of vessel owners and operators and the Lake Carriers' and Dominion Marine Associations, in a concerted effort to abate the vessel smoke problem. In the summer of 1950, the Lake Carriers' and Dominion Marine Associations, Bituminous Coal Research, Inc., and the Coal Producers Committee for Smoke Abatement had organized the Great Lakes Air Pollution Abatement Program (GLAPAP) in order to assist in abatement of smoke from vessels and to cooperate with the International Joint Commission and its Technical Advisory Board in the study of smoke emission control measures for the shipping industry. The Engineering Advisory Committee of GLAPAP studied various overfire steam-air jet installations, established improved fuel specifications for coal-burning vessels, and distributed manuals on combustion to officers of vessels and pamphlets on steam-air jet installations to owners and operators of Great Lakes vessels. Lectures on smokeless firing methods were given at schools conducted by the Lake Carriers' and Dominion Marine Associations.

Since 1952, the International Joint Commission has annually adopted objectives as to the amount of smoke emission considered satisfactory for various types of fuel-burning equipment installed in vessels. During the first three years, "Smoke Emission Objectives" were made stricter each year but have remained the same since 1955. Eventually, it is hoped that smoke from all vessels will be brought within the limits prescribed by the "Example Sections for a Smoke Regulation Ordinance" recommended by the American Society of Mechanical Engineers. The smoke emission limits in these "Example Sections" are the same as those of the smoke regulation ordinances of the cities of Detroit and Windsor.

On June 5, 1953, the International Joint Commission held a second public hearing at Detroit. The Technical Advisory Board reviewed progress in the study of air pollution, abatement of smoke from vessels, and remedial measures sponsored by the agencies under the Great Lakes Air Pollution Abatement Program.

Since 1952, smoke emission observations and the "Smoke Emission Objectives" have formed the cornerstone of a voluntary control program. Other activities of the Board in the vessel smoke control program have included periodic letters to vessel owners and operators stating the smoke performance of vessels; prompt notification by radiotelephone to Detroit River vessel captains of failure to comply with objectives; and meetings with air pollution control officers of Detroit, Windsor, and other municipalities along the river. Conferences have also been held with the Engineering Advisory Committee of GLAPAP.

Thanks are due to the Lake Carriers Association, the Dominion Marine Association, GLAPAP, and municipal control agencies for their sustained cooperation and support of the voluntary control program. The GLAPAP organization has also assisted by printing the annual smoke performance reports and in bearing the expense of radiotelephone service.

STUDY OF SOURCES, NATURE, AND EXTENT OF POLLUTION

FIELD SURVEYS

On the Canadian side, field sampling surveys to determine concentrations and area-wide distribution of particulate and gaseous pollutants and to collect necessary samples for laboratory studies were under the direct supervision of Messrs. Cave and Cole at the Windsor Laboratory.

The United States field surveys were carried out under the supervision of Messrs. Clayton and Glever. Valuable assistance was rendered by Dr. Fredrick, Director of the Detroit Bureau of Industrial Hygiene, and Mr. Linsky, Chief Smoke Inspector of the Detroit Bureau of Smoke Inspection and Abatement, and members of their staffs.

Observations of dustfall at 20 stations in the Greater Windsor area were carried out between 1951 and 1957. Similar data from 20 sampling stations in Detroit have been gathered for many years by the Detroit Bureau of Smoke Inspection and Abatement and were made available to the Technical Advisory Board.

High volume samplers were used to collect suspended particulate matter from the air. As many as 30 were operated simultaneously to study fluctuations of suspended particulate pollution levels with geographical location and meteorological factors. These samplers were also used for a short period along both banks of the Detroit River to determine transboundary flow of pollution.

Other studies of air-borne particulates have depended upon the evaluation of filtered deposits, by means of optical density measurements which could be expressed in terms of an index of the soiling power of impurities.

On the Canadian side four to five continuous field sampling stations for determination of sulfur dioxide were maintained from the autumn of 1950 until 1957. On the Detroit side measurements of sulfur dioxide were conducted at periodic intervals between 1951 and the first half of 1953. From July 1953 to 1957 the Detroit Bureau of Industrial Hygiene collected sulfur dioxide data continuously and made the data available to the Board.

Other studies on a limited basis have dealt with the atmospheric content of aldehydes, oxidants and nitrogen dioxide, etc. The Detroit Bureau of Industrial Hygiene also studied levels of natural radioactivity of particulate pollution.

LABORATORY INVESTIGATIONS

A large number of samples of air-borne particulates were analyzed by Drs. Byers and Keenan of the Division of Occupational Health, United States Public Health Service, Cincinnati, Ohio. The results provided comprehensive information on 22 metallic elements and sulfates, fluorides and chlorides in particulate matter.

Laboratory studies on the Canadian side were under the direction of Dr. Katz. Dr. Shore conducted research on identification of crystalline components of air-borne particulate matter by x-ray diffraction technique; size distribution and shape of dust particles by standard light microscope and electron microscope; and on isolation of polynuclear aromatic hydrocarbons, including carcinogenic compounds, by chromatographic and ultraviolet absorption techniques. Mr. Moore and Mr. Cole examined the accuracy of several methods for determination of atmospheric sulfur dioxide and investigated methods for the concurrent analysis of air for sulfur dioxide and nitrogen dioxide. Certain relationships between light absorption of particulate deposits on filter paper and mass concentration were studied by Mr. Ferguson and Mr. Sanderson. The effects of sulfur dioxide and the urban atmosphere on the chlorophyll and pheophytin content of leaves of plants were examined by Dr. Shore.

OTHER STUDIES

During the summer months of 1956, a group of professors, graduate students and others associated with Wayne State University in Detroit were employed to prepare information needed to complete certain portions of the final report. Under the guidance of the United States Technical Advisory Board, Professor H. G. Donnelly supervised collection of information concerning pollution emissions from land-based sources. Professor W. R. Monat supervised preparation of information concerning the general description of the study area, legislation and regulatory practices pertinent to air pollution in the United States portion of the study area and assembly of information used in preparation of the climatological summary. During the summer and fall of 1956, the Michigan State Department of Health, Division of Occupational Health, under terms of a contract with the United States Public Health Service negotiated for other purposes, prepared an inventory of air pollution emissions arising from industrial establishments in the United States portion of the study area, excluding those in the city of Detroit. Work on the inventory was supervised by Mr. B. D. Bloomfield and the information was used along with that collected by Professor Donnely's group.

METEOROLOGICAL STUDIES

Messrs. Baynton, White, and Oak studied the relationship between meteorology and air pollution using data from existing United States Weather Bureau and Dominion Meteorological Service Stations. These studies used data on wind speed and direction, temperature, humidity, precipitation, and inversion frequency. Data concerning inversion frequency were derived from radiosonde observations made at Mount Clemens, Michigan and Toledo, Ohio. Mr. F. Pooler, Jr. of the U. S. Weather Bureau, Meteorological Unit working with the United States Public Health Service in Cincinnati, did additional work on this phase of the study in 1956 and 1957.

As the investigation progressed, specialized meteorological studies of a more localized character were necessary to correlate pollution levels with weather factors. Additional meteorological instruments were installed in Windsor by Mr. Baynton, and recording temperature equipment was installed at four elevations on a Detroit television tower owned by the Storer Broadcasting Company. Thus, vertical temperature profiles were determined within the study area.

Mr. Baynton studied the relationships between particulate pollution levels and weather elements by means of a statistical regression analysis. Other correlations dealt with diurnal variation of sulfur dioxide and particulate pollution, magnitude of exotic pollution, and dependency of transboundary flow of particulate pollution on wind speed and direction.

THE HEALTH STUDY

The Technical Advisory Board approached various governmental agencies and interested them in undertaking an investigation of the effects of air pollution on public health. Preliminary groundwork, planning, design of methods, staffing, and other details were accomplished in 1951, 1952, and the early part of 1953. Collection of data for the health study was commenced in July 1953 and completed in July 1955 as a joint effort of participating agencies in both countries.

UNITED STATES

Early planning of the health study and selection of areas in Detroit having similar socio-economic status were carried out by Drs. W. M. Gafafer and Hugh Brinton of the United States Public Health Service in 1951 and 1952. A preliminary survey of principal sources of emission in Detroit was made with the assistance of maps locating industrial properties, prepared in the office of the City Assessor. Inspectors of the Detroit Bureau of Smoke Inspection and Abatement determined, through observation, which of the plants were making an appreciable contribution to pollution. From this information, areas representing high pollution and low pollution were determined. On the basis of socio-economic data, 28 areas were selected for a six-week air sampling survey during the summer of 1951, using 31 high volume air sampler stations. The survey of sources and study of air pollution levels were coordinated by Mr. Clayton. In all, 1,500 samples of particulate pollution were collected and approximately 30,000 analyses were made by the Division of Occupational Health of the Public Health Service. Assessment of the air sampling and socio-economic data and further preliminary work in 1952 led to the selection of four study areas of 150 household units each for the morbidity study.

Responsibility for the conduct of the health study on the United States side was assumed by the Detroit Department of Health under Dr. J. G. Molner, Health Commissioner, with Dr. Anderson, Deputy Health Commissioner, in overall charge of the sickness survey. Members of the Bureau of Industrial Hygiene staff under Dr. Fredrick undertook the environmental air pollution measurements at sampling stations within health study areas. Five full-time enumerators were employed by the Detroit Department of Health to gather the sickness data. Dr. A. S. Robson of the Communicable Disease Center, United States Public Health Service, also participated in this work during the first year of the study. The data were reviewed and processed under the supervision of Mr. James Oliver, Chief of the Statistical Division of the Detroit Department of Health. Later in the study funds were made available to the Department from the United States Public Health Service to secure machine data processing services and the services of consultants for further evaluation of the methods used and the data obtained.

CANADA

In the fall of 1951, a six-week study was made of particulate pollution levels on a continuous basis at 25 sampling stations in Greater Windsor.

A considerable number of samples were forwarded, for detailed analysis, to the Division of Occupational Health of the United States Public Health Service at Cincinnati, Ohio. Assessment of these data together with results of dustfall determinations at 20 sampling sites and continuous sulfur dioxide observations at four stations over a period of two years led to delineation of areas of heavy, moderate and low pollution within the study area. These surveys were carried out by the staff of the Windsor Laboratory of the Technical Advisory Board under direction of Dr. Katz and field supervision of Mr. Cave.

Responsibility for planning and organization of the Canadian part of the health study was assumed by the Division of Epidemiology in close cooperation with the Occupational Health Division and Research and Statistics Division, all of the Department of National Health and Welfare, Ottawa.

Drs. Arthur F.W. Peart and G.H. Josie conducted the preliminary assessment of socio-economic and environmental data in 1952 as a basis for matching population groups of households in high and low pollution areas in Windsor. Two hundred households were selected in high and low pollution areas in Windsor. For control purposes, an air pollution survey was made of a number of non-industrial towns within about 40 miles from Windsor. Kingsville and Harrow were chosen and 100 households were selected in each town. After the first year of the health study 200 households from the town of Simcoe, were added as an additional control. The Dominion Bureau of Statistics assisted in the selection of the sample households.

Dr. Watkinson, Principal Medical Officer of the Department of National Health and Welfare, acted as coordinator of the health study. Dr. Peart resigned as Cheif of the Epidemiology Division in 1953 and his activities in the health study were assumed by Dr. E. H. Lossing. For administrative purposes, funds for the work were provided to the Industrial Hygiene Division of the Ontario Department of Health under the Federal Health Grants system, through the active assistance of Dr. R. B. Sutherland. The field staff consisted of two full-time supervisors and 18 to 25 part-time enumerators, under direction of Mr. W. L. McEwen of the Epidemiology Division. Assessment of sickness data and statistical correlations were carried out by Dr. Josie and staff of the Research and Statistics Division.

Dr. John Howie, Medical Officer of Health of the City of Windsor cooperated in every possible way and office accomodations for field staff were made available by the city health department. The Medical Officers of Health in the control areas of Harrow, Kingsville, and Simcoe also extended hearty cooperation.

STUDY OF VEGETATION

The effects of air pollution on vegetation were investigated by a committee under the chairmanship of Mr. Frank Vadick, Assistant Superintendent of Forestry and Landscape of the Detroit Department of Parks and Recreation. On the United States side disease symptons of various plant species in relation to air pollution were observed and diagnosed by Professor A.G. Norman and Mr. E. Steiner of the Department of Botany, University of Michigan. On the Canadian side, a diagnostic study was conducted by Dr. L. W. Koch, Director of Plant Pathology, Dominion Experimental Station, Harrow, Ontario. A limited survey of the condition of tree species was also made by Mr. A. W. McCallum, Forest Pathologist, Department of Agriculture, Ottawa. The Technical Advisory Board field staff assisted in the collection and analysis of samples. The vegetation surveys were carried out mainly in the growing seasons of 1953 and 1954, although Dr. Koch had been concerned for several years earlier with symptons, which had been attributed to atmospheric pollution, in orchards and farms adjacent to Windsor and Amherstburg. In the fall of 1956, Dr. C.S. Brandt, Agricultural Liaison Officer of the United States Department of Agriculture with United States Public Health Service, Community Air Pollution Program at Cincinnati, prepared a summary of the various studies made of relationships between air pollution and damage to vegetation.

MISCELLANEOUS STUDIES

To determine the degree to which haze from atmospheric contamination reduces visibility and, therefore, affects safety in transportation on land, water, and air, studies of light transmission were made in the United States portion of the study area by Messrs. Clayton and Giever. Intensity of solar illumination was studied by Messrs. Baynton and Munn in the Canadian area.

Exact determination of economic effects is a difficult matter involving long term studies of corrosion of metals, deterioration of brick work and other building materials, and discoloration and deterioration of fabrics, paints, and other products. The Board was not able to conduct a study of the economic effects of pollution. Mr. Carl A. Lindstrom, Sanitary Engineer, of the United States Public Health Service at the Robert A. Taft Sanitary Engineering Center, reviewed and evaluated the results of studies done by others in both the United States and Great Britain to arrive at findings with respect to the study area as reported herein.

An investigation was made of the remedial measures available to vessel owners and operators in the conversion of hand-fired, coal-burning equipment to automatic combustion. The relative costs of various types of installations were assessed. Mr. Paul Kenline, Assistant Sanitary Engineer of the United States Public Health Service at the Robert A. Taft Sanitary Engineering Center, collected and reviewed information relative to these matters in 1956. Fine cooperation was received from vessel owners, equipment manufacturers, research groups, GLAPAP and others.

PROGRESS REPORTS AND TECHNICAL PAPERS

An account of the various studies completed under the Terms of Reference if given only in condensed form in this final report. The dedetails of the work of the Technical Advisory Board have been presented to the Commission periodically in a series of documents which are listed in Appendix A of this chapter. In essence, this list consists of three major series of reports:

1. Reports on progress of investigations relating to vessel smoke and its abatement.
2. Reports on the progress of environmental studies of air pollution; reports on chemical, spectrographic, and other studies of the nature and composition of contaminants; and reports of meteological investigations.
3. Reports on progress in the study of the effects of contaminants on health and vegetation.

A number of technical papers arising out of the investigations were also prepared and presented at various times to scientific organizations. A detailed list of these is given in Appendix B of this chapter.

APPENDIX A

REPORTS OF INVESTIGATIONS OF THE TECHNICAL ADVISORY BOARD ON AIR POLLUTION SUBMITTED TO THE INTERNATIONAL JOINT COMMISSION

VESSEL SMOKE AND ITS ABATEMENT

1. First Interim Report - October 1949
2. Smoke Emission from Vessels, Navigation Season 1949 (See Canadian Section Progress Report No. 1 of Section "B" - April 1950).
3. Second Interim Report - October 1950
4. Tabulation of Data on Smoke Emission from Vessels - June 22 to September 22, 1950. Report Presented at Public Hearing of the Commission, Detroit, October 18-19, 1950.
5. Information (Firing Equipment) on Vessels Operating on Detroit River and Tributaries. Report Presented at Public Hearing of the Commission, Detroit, October 18-19, 1950.
6. Interim Report - September 27, 1951.
7. Summary of Studies, Navigation Seasons 1949 - 1951. Presented April 1952.
8. Smoke Performance of Vessels, Navigation Season 1952. Report dated February 1953.
9. Smoke Performance of Vessels, Navigation Season 1953. Report dated February 1954.
10. Vessel Smoke Abatement Activities during 1953. (U. S. Section Report) Report dated March 15, 1954.
11. Smoke Performance of Vessels, Navigation Season 1954. Report dated February, 1955.
12. Smoke Performance of Vessels, Navigation Season 1955. Report dated March 1956.
13. Smoke Performance of Vessels, Navigation Season 1956. Report dated March 1957.
14. Smoke Performance of Vessels, Navigation Season 1957. Report dated March 1958.

ENVIRONMENTAL, CHEMICAL AND METEOROLOGICAL INVESTIGATIONS

1. Investigations of Canadian Section

Progress Report No. 1 - April, 1950
Progress Report No. 2 - April, 1951
Progress Report No. 3 - September, 1952
Progress Report No. 4 - April, 1953
Progress Report No. 5 - July, 1953
Progress Report No. 6 - October, 1953
Progress Report No. 7 - April, 1954
Progress Report No. 8 - April, 1955
Progress Report No. 9 - October, 1955
Progress Report No. 10 - September, 1956

2. Investigations of United States Section

Report on 1951 Environmental Findings - March, 1953

Report on 1952 Environmental Findings - January, 1954

Report on 1953 Environmental Studies - April, 1955

Report on 1953 Environmental Findings - Section II, April, 1955

3. Joint Reports

Joint Progress Report No. 1 - April, 1950

Joint Progress Report No. 2 - April, 1951

Joint Progress Report - September, 1954

Appraisal of Investigations, Interim Report - February, 1955

HEALTH STUDY

Statement of Progress during period April 1952 - April 1953. Report dated March 26, 1953.

Statement of Progress, presented by Dr. Anderson at Meeting of Commission, Washington, D. C., April, 1954.

Progress Report, Detroit-Windsor Health Study: 1953 - 1954, April, 1954.

Detroit - Windsor Air Pollution Health Study; Field Methods 1953 - 1955, April, 1956.

Analysis and Results of the Air Pollution Health Study in Canada, March, 1956.

APPENDIX B

TECHNICAL PAPERS PRESENTED AT CONFERENCES OF SCIENTIFIC ORGANIZATIONS

1. Katz, Morris, "Atmospheric Pollution and Its Control", Modern Sanitation, Part I, June 1950; Part II, July 1950.

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Chapter IV

GENERAL DESCRIPTION OF THE DETROIT RIVER AREA

DESCRIPTION OF THE STUDY AREA

The Detroit River is the connecting link between Lake Erie and Lake St. Clair, a small lake which, in turn, is connected to Lake Huron by the St. Clair River (Figure IV-1). The area included in this study extends generally from the south end of Grosse Ile to the east end of Peach Island in the Detroit River and roughly 15 miles inland on both sides of the river (Figure IV-2). In the United States, this area includes all of Wayne County and the southern portions of Macomb and Oakland Counties in Michigan. In Canada, it includes the western portion of Essex County in Ontario. There are over 70 cities, townships, and villages within the area, with a population of nearly 3,500,000 people. On the American side of the river the area is demacrated by the following boundaries: Fifteen Mile Road, running westward from Lake St. Clair to Telegraph Road; Telegraph Road southward to Eight Mile Road (Base Line Road), which is the northern boundary of Wayne County; and the whole of Wayne County. On the Canadian side of the river, the area includes that portion of Essex County lying west of an imaginary line running in a southerly direction from the mouth of the Puce River at Lake St. Clair to Lake Erie.

For the most part, the study area is flat and rises gradually away from both sides of the Detroit River. On the Canadian side, elevations along the river are almost uniformly 575 feet above sea level. As the topographic map (Figure IV-3) indicates, the Canadian side is virtually flat but does increase in elevation gradually until it reaches 600 to 625 feet east of Windsor and Sandwich. There are no irregular rises.

On the American side, elevations along the river vary from 575 to 590 feet. Slight rises exist and an elevation of about 600 feet is reached gradually along a line roughly paralleling the river. The United States study area elevation increases inland from the river throughout until it attains 650 feet about halfway across the area. It then begins to rise more sharply and irregularly until it reaches between 800 and 900 feet at the western and northern limits. No topographic features exist which would considerably restrict dispersion of air pollutants.

DESCRIPTION OF THE DETROIT RIVER

The Detroit River begins just east of Peach Island at the southern end of Lake St. Clair (Figure IV-1). It flows in a westerly direction and then in a southerly direction until it reaches its mouth at Lake Erie--a distance of 31 miles. The "upper river," from the head to the upstream end of Fighting Island, is characterized by a rather uniform width of 2400 feet. Belle Isle and Peach Island are located near the head of the river. The "lower river," beginning at Fighting Island, broadens out and is characterized by many islands and shallow expanses. The two largest islands in the "lower river" are Fighting Island and Grosse Ile.

The major shipping channels in the Detroit River (Figure IV-4) closely follow the international boundary and, in passing through the river, a ship may move from United States to Canadian waters several times. Except for the lower ten miles of the river, before it empties into Lake Erie, the river's channels are two-way, carrying both upbound and downbound traffic. They vary in width from 200 to 1200 feet, in length from 600 to 3700 feet, and in depth from 20 to 27 feet. The St. Lawrence Seaway Project proposes to provide a minimum depth of 27 feet for all the Detroit River channels as well as for all other shipping channels of the Great Lakes and St. Lawrence waterways.

Although the river current is not constant and at times flow reversals have occurred, the United States Lake Survey has reported that the average current velocity in the section of the river from the foot of Belle Isle to the head of Fighting Island is 1.5 miles per hour. Opposite Amherstburg in the Amherstburg and Ballards Reef Channels, which carry 44 percent of the river flow at that point, the velocity averages 2 miles per hour.

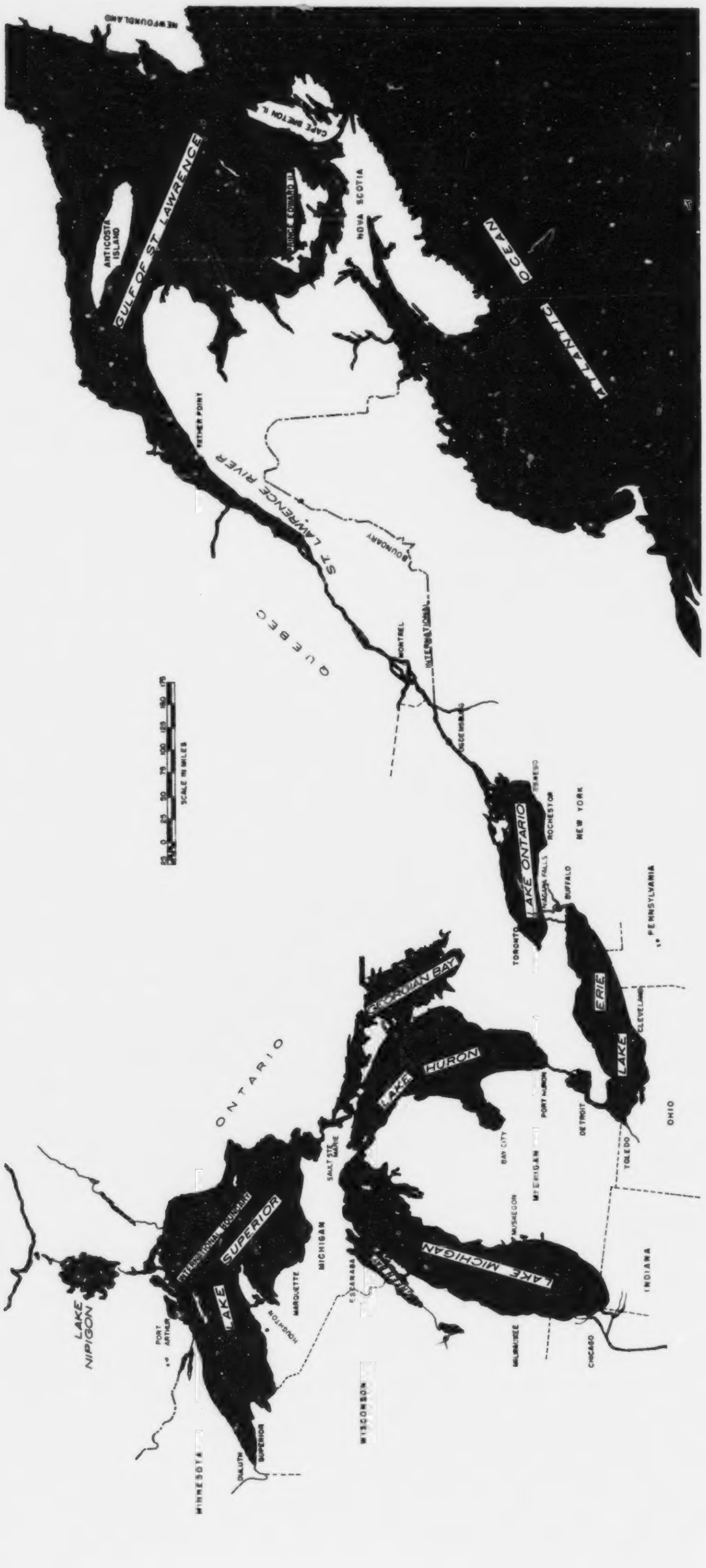
NEWFOUNDLAND
CAPE BRETON I.
GULF OF ST. LAWRENCE
ANTICOSTI ISLAND
PRINCE EDWARD I.
NOVA SCOTIA
ATLANTIC OCEAN
FATHER POINT
ST. LAWRENCE RIVER
INTERNATIONAL BOUNDARY
QUEBEC
MONTREAL
OGDENSBURG
OSWEGO
ROCHESTER
NEW YORK
LAKE ONTARIO
NIAGARA FALLS
BUFFALO
TORONTO
PENNSYLVANIA
LAKE ERIE
CLEVELAND
GEORGIAN BAY
LAKE HURON
PORT HURON
DETROIT
TOLEDO
OHIO
ONTARIO
BAY CITY
MICHIGAN
SAULT STE MARIE
MUSKEGON
LAKE MICHIGAN
INDIANA
CHICAGO
MILWAUKEE
ESCANABA
GREEN BAY
LAKE SUPERIOR
INTERNATIONAL BOUNDARY
MARQUETTE
HOUGHTON
PORT ARTHUR
LAKE NIPIGON
WISCONSIN
MINNESOTA
DULUTH
SUPERIOR
SCALE IN MILES
25 0 25 50 75 100 125 150 175

Figure IV-1. Great Lakes and St. Lawrence Seaway

1. PLYMOUTH
2. LIVONIA
3. DETROIT
4. HIGHLAND PARK
5. HAMTRAMCK
6. LATHRUP VILLAGE
7. BIRMINGHAM
8. CLAWSON
9. ROYAL OAK
10. BERKLEY
11. HUNTINGTON WOODS
12. PLEASANT RIDGE
13. OAK PARK
14. FERNDALE
15. HAZEL PARK
16. MADISON HEIGHTS
17. WARREN
18. CENTER LINE
19. FRASER
20. ROSEVILLE
21. EAST DETROIT
22. ST. CLAIR SHORES
23. HARPER WOODS
24. GROSSE POINT WOODS
25. GROSSE POINT SHORES
26. GROSSE POINT FARMS
27. GROSSE POINT
28. GROSSE POINT PARK
29. ST. CLAIR BEACH
30. TECUMSEH
31. RIVERSIDE
32. WINDSOR
33. OJIBWAY
34. LA SALLE
35. AMHERSTBURG
36. AULD
37. MC GREGOR
38. MAIDSTONE
39. ESSEX
40. HARROW
41. NORTH MAIDEN
42. ROCKWOOD
43. GIBRALTER
44. FLAT ROCK
45. TRENTON
46. RIVERVIEW
47. WYANDOTTE
48. LINCOLN PARK
49. ENCORSE
50. ALLEN PARK
51. RIVER ROUGE
52. MELVINDALE
53. DEARBORN
54. INKSTER
55. GARDEN CITY
56. WAYNE
57. ROMULUS
58. PUCE
59. BELLE RIVER
60. ELMSTEAD

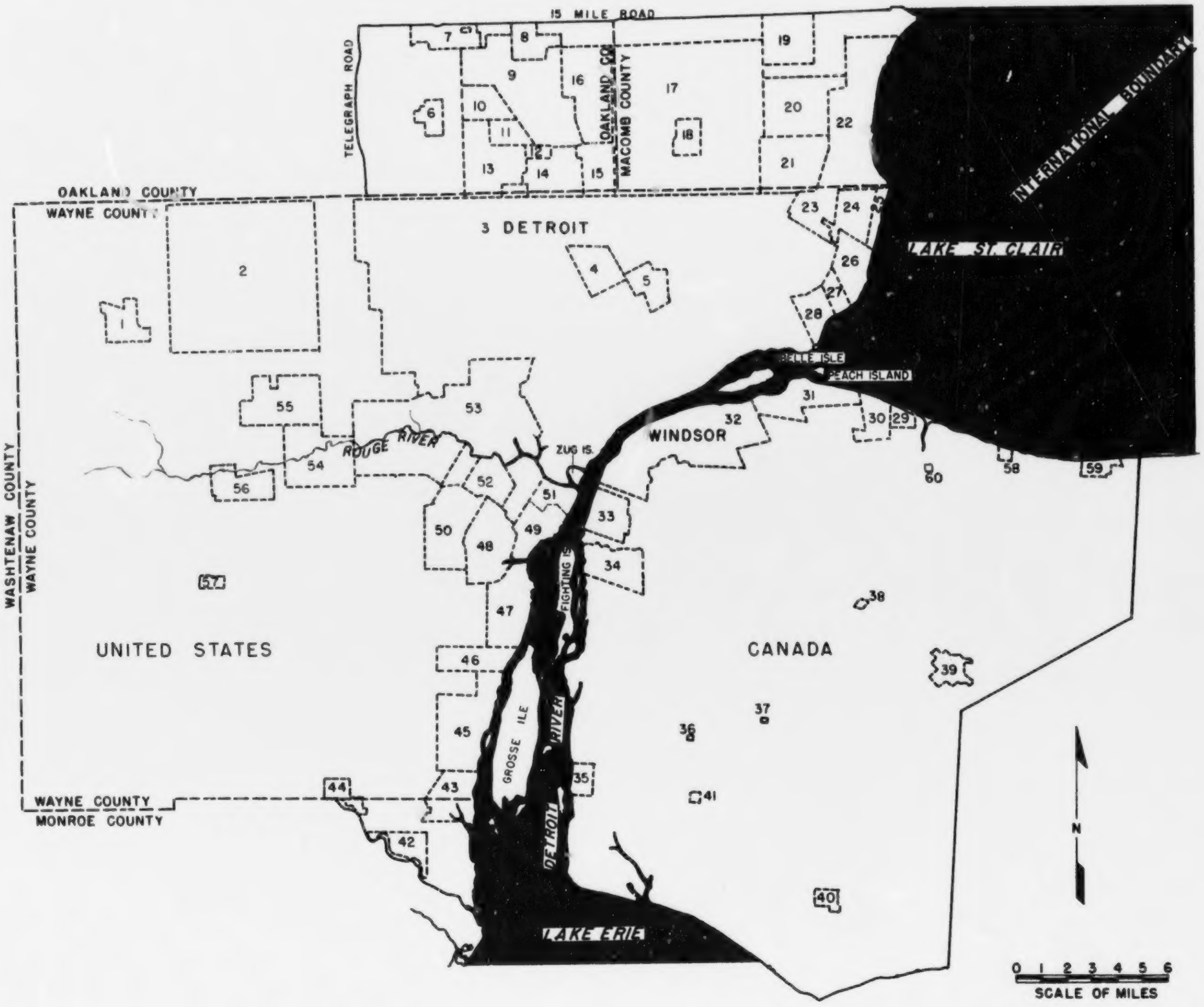
15 MILE ROAD
TELEGRAPH ROAD
OAKLAND CO
MACOMB COUNTY
OAKLAND COUNTY
WAYNE COUNTY
WASHTENAW COUNTY
WAYNE COUNTY
MONROE COUNTY
3 DETROIT
ROUGE RIVER
ZUG IS.
BELLE ISLE
PEACH ISLAND
LAKE ST. CLAIR
INTERNATIONAL BOUNDARY
WINDSOR
FIGHTING IS
GROSSE ILE
DETROIT RIVER
LAKE ERIE
UNITED STATES
CANADA
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Figure IV-2. The Detroit-Windsor Air Pollution Study Area

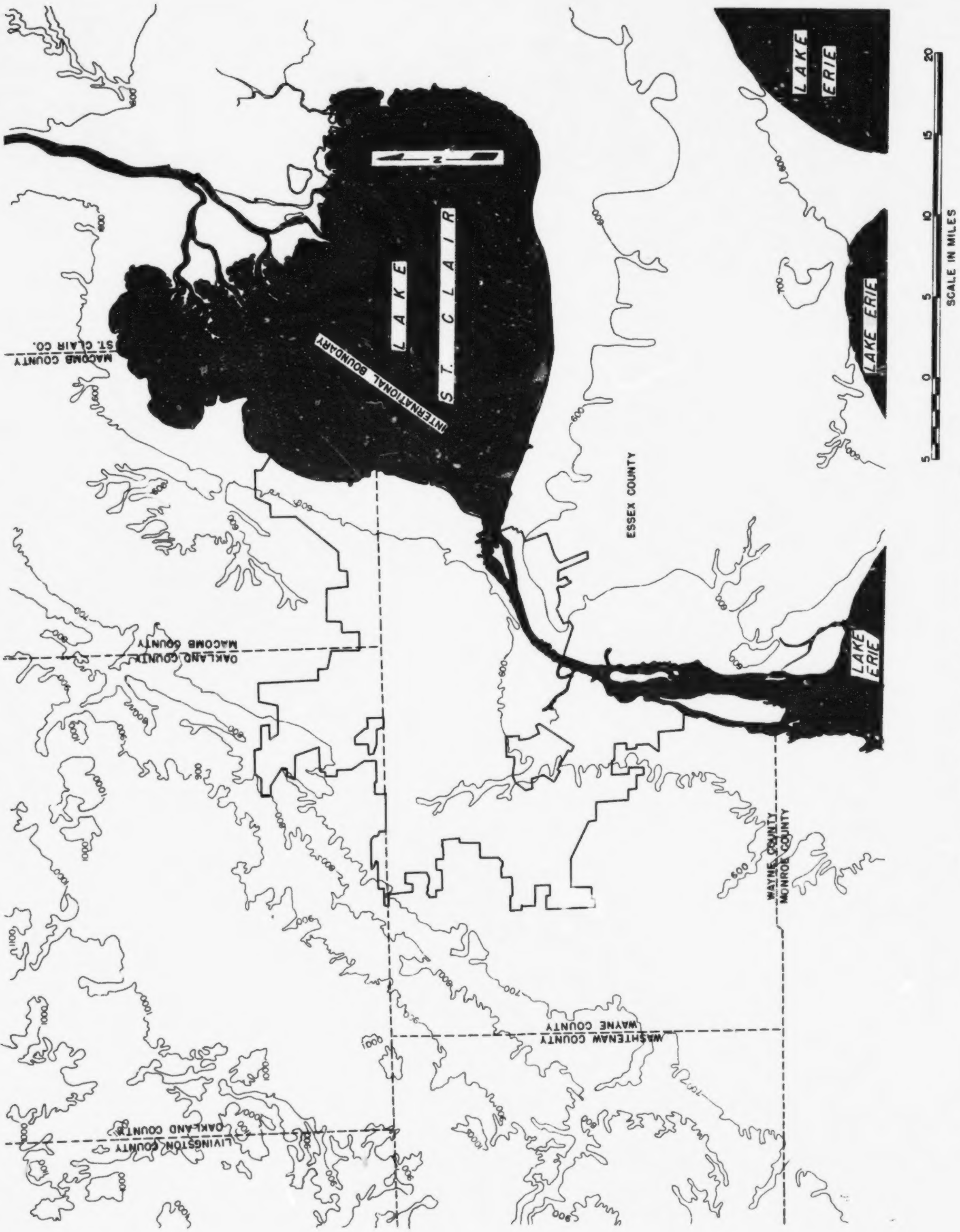
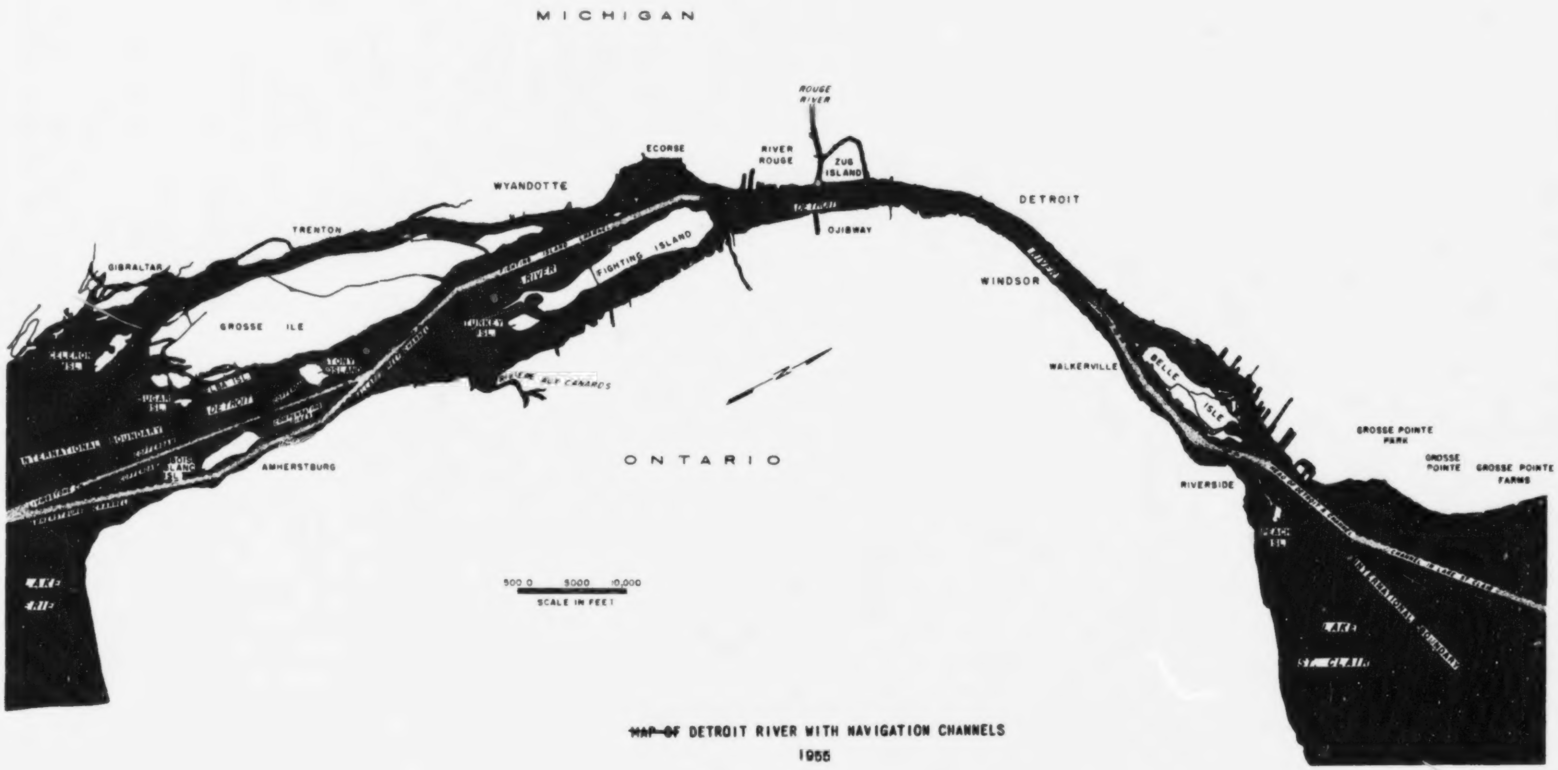

LAKE ST. CLAIR
N
INTERNATIONAL BOUNDARY
MACOMB COUNTY
ST. CLAIR CO.
OAKLAND COUNTY
MACOMB COUNTY
ESSEX COUNTY
LAKE ERIE
LAKE ERIE
LAKE ERIE
WAYNE COUNTY
MONROE COUNTY
WASHTENAW COUNTY
WAYNE COUNTY
LIVINGSTON COUNTY
OAKLAND COUNTY
600
700
800
900
1000
1100
5 0 5 10 15 20
SCALE IN MILES

Figure IV-3. Topography of the Detroit-Windsor Region


MICHIGAN
ROUGE RIVER
ECORSE
RIVER ROUGE
ZUG ISLAND
WYANDOTTE
DETROIT
TRENTON
OJIBWAY
GIBRALTAR
FIGHTING ISLAND
RIVER
WINDSOR
GROSSE ILE
TURKEY ISL.
CELERON ISL.
TONY ISLAND
ELBA ISL.
SUGAR ISL.
DETROIT
RIVIERE AUX CANARDS
WALKERVILLE
BELLE ISLE
INTERNATIONAL BOUNDARY
BOIS BLANC ISL.
AMHERSTBURG
ONTARIO
GROSSE POINTE PARK
GROSSE POINTE
GROSSE POINTE FARMS
RIVERSIDE
PEACH ISL.
INTERNATIONAL BOUNDARY
LAKE ST. CLAIR
LAKE ERIE
500 0 5000 10,000
SCALE IN FEET

~~MAP OF~~ DETROIT RIVER WITH NAVIGATION CHANNELS
1955

Figure IV-4. Detroit River with Navigation Channels

The only major navigable tributary of the Detroit River is the Rouge River, which empties into the Detroit River on the United States side at Zug Island about mid-point in the length of the river. Of its 32-mile main stream, only the lower 3.5 miles through the Short Cut Canal have been dredged for use of traffic serving industries in the area. The Short Cut Canal is an artificial, 3000-foot connection which eliminates an S-shaped curve in the lower Rouge River and shortens the distance to upstream points by one mile. The river has a depth of 18 to 25 feet. Although not a part of the Detroit River proper, the channels of the Rouge River play a significant role in the over-all traffic pattern of the area. The Rouge River is the waterway for the heavily industrialized area, south and west of Detroit, which includes Dearborn, Ecorse, and River Rouge, and particularly the mammoth Ford plants at River Rouge and Dearborn.

Other tributaries are the Ecorse River, which enters opposite Fighting Island, and the Huron River, which flows into the broad mouth of the Detroit River at Lake Erie. Both tributaries are in the United States.

RIVER USE AND DEVELOPMENT

HISTORICAL SUMMARY

Commercial traffic on the Detroit River dates from the second half of the 18th Century. Although sailing vessels dominated Great Lakes transportation during much of the 19th Century, the first regularly scheduled steamboat began running between Detroit and Buffalo in 1818. By 1900, over 1700 steam vessels were engaged in Great Lakes shipping. Regular runs were made by such vessels between Chicago and the lower lakes ports by 1850; the opening of St. Mary's Ship Canal in 1855 permitted passage of the largest lake vessels into Lake Superior. This passage facilitated utilization of the rich iron ore, discovered in Northern Michigan, Wisconsin, and Minnesota during the 1840's, because the ore could henceforth be shipped to steel mills closer to coal supplies in Southern Michigan, Ohio, Pennsylvania, and New York. Today, by far the larger number of vessels plying the Great Lakes routes through the Detroit River are "bulk-cargo" crafts carrying ore, grain, coal, stone, and gravel.

PORTS ALONG THE DETROIT RIVER

There are 160 piers, wharves, and docks in the Detroit River area. A large majority of these are located on the American side of the river at Detroit, River Rouge, Ecorse, Wyandotte, Trenton, and Riverview. These American facilities are known collectively as the "Port of Detroit." The Port of Detroit District is coextensive with the limits of Wayne County and, therefore, encompasses all facilities on the American side of the Detroit River. In Canada, there are about 12 piers, wharves, and docks. They are located at Windsor, Walkerville, and Amherstburg.

Port facilities along the City of Detroit frontage of the river consist of somewhat less than 100 piers, wharves, and docks. Most of these are used for the handling of cargo for industries located on the river. Two public cargo terminals are located at detroit. Port facilities in the City of Detroit handle about 3500 vessels per year, a greater number than any other port on the river. These vessels bring in about 5,400,000 short tons of cargo and take out about 460,000 short tons, a quantity exceeded only by the facilities at River Rouge (Table IV-1). Anchorages at these facilities range from 18 to 25 feet in depth and, therefore, can accomodate most vessels operating in the Great Lakes.

Port facilities at River Rouge accomodate about 1800 vessels per year which bring in about 8,500,000 short tons of cargo and take out about 350,000 short tons (Table IV-2). The high tonnage of incoming cargo, the greatest of any facility in the area, is due to the fact that bulk cargoes constitute most of the traffic coming into the docks. There are no general cargo or public terminals at River Rouge or along the Rouge River, although nearly one-third of all facilities at the Port of Detroit are located along this tributary--over 40 piers, docks, or wharves. The major terminals on the Rouge River are those at the Ford Motor Company's vast installations at River Rouge and Dearborn and petroleum tank farms. Anchorage depths are about 21 feet, some being shallower.

Ecorse contains the only shipbuilding and repair docks in the Detroit area at the present time. It also possesses one of the three general public cargo terminals on the American side of the river. The other major facility located at Ecorse is maintained by the Great Lakes Steel

Table IV-1. Traffic at Detroit City Port Facilities

Year	Tonnage* (Short tons)		Vessel traffic					
	Inbound Receipts & Imports	Outbound Exports & Shipments	Inbound			Outbound		
			Steamers	Motor Vessels	Barges	Steamers	Motor Vessels	Barges
1944	5,038,219	117,402	2,446	0	530	2,450	0	530
1945	4,904,038	65,672	2,454	1	251	2,449	1	251
1946	4,319,576	310,789	2,690	7	214	2,690	7	214
1947	5,072,712	421,551	3,044	22	203	3,044	22	203
1948	4,982,445	441,249	3,270	44	260	3,269	44	260
1949	4,412,045	680,787	3,870	87	238	3,871	88	237
1950	5,133,353	809,521	3,679	108	249	3,678	109	249
1951	6,320,550	627,119	3,393	129	295	3,395	128	295
1952	5,454,347	483,095	3,000	173	321	3,004	173	322
1953	6,987,743	661,124	3,417	236	393	3,411	236	392
1954	6,510,571	439,393	2,517	350	404	2,516	349	407

*Does not include local traffic.

Source: U. S. Corps of Engineers

Table IV-2. Traffic at River Rouge Port Facilities

Year	Tonnage* (Short tons)		Vessel traffic					
	Inbound Receipts & Imports	Outbound Exports & Shipments	Inbound			Outbound		
			Steamers	Motor Vessels	Barges	Steamers	Motor Vessels	Barges
1944	7,280,414	301,523	1,287	121	499	1,290	122	497
1945	6,664,484	257,570	1,117	97	424	1,118	97	429
1946	6,869,721	222,423	1,125	138	105	1,124	138	105
1947	7,942,495	227,142	1,302	180	86	1,302	180	84
1948	9,003,535	197,935	1,165	350	276	1,165	350	275
1949	7,431,958	390,660	1,022	319	247	1,022	319	247
1950	10,464,466	210,357	1,208	713	264	1,209	711	265
1951	10,231,790	316,885	1,132	543	341	1,132	543	339
1952	10,438,268	446,710	1,208	477	502	1,208	477	499
1953	11,202,388	484,932	1,248	484	500	1,247	484	501
1954	7,021,268	829,233	909	251	308	908	248	324

*Does not include local traffic.

Source: U. S. Corps of Engineers

Corporation, the primary steel producer in the Detroit area. About 1,300,000 short tons of cargo are brought in through these facilities per year and about 137,000 short tons are shipped out. Approximately 1150 vessels use the port each year (Table IV-3).

The major terminals at Wyandotte are primarily for bulk cargo and are maintained by industrial establishments, the largest of which are operated by the Wyandotte Chemical Company and the Pennsylvania Salt Company. About 500 vessels use these terminals each year, bringing in close to 2,400,000 short tons of cargo and taking out about 35,000 short tons (Table IV-4). The channel leading to these facilities is 21 feet in depth, too shallow for ships of greater draft.

Traffic at Riverview and Trenton amounts to about 800,000 short tons per year of inbound cargo and 150,000 short tons of outgoing cargo, carried by about 340 vessels (Table IV-5). Nearly all of this traffic is at Trenton, while traffic at Riverview is minor. The depth of the channel into the Trenton and Riverview port facilities is 21 feet; anchorage depths are 21 and 18 feet respectively.

Canadian wharves, docks, and piers are located at Windsor, Walkerville, and Amherstburg. There are about 12 in all. The facilities at Windsor and Walkerville handle about 800 vessels per year which bring in about 2,500,000 short tons of cargo (Table IV-6). The major public and general facility at Windsor and Walkerville is the Northwest Steamships Ltd. dock, while other facilities of importance are operated by Hiram Walker & Sons, Ford Motor Company of Canada, Canada Steamship Lines, and the Ontario Hydro-Electric Power Commission. The anchorages of these facilities have depths of 18 to 24 feet.

Port facilities at Amherstburg are accessible for most vessels only through the Amherstburg and Ballards Reef channels. The controlling depth of both these channels is 21 feet and, therefore, deeper draft vessels cannot use the facilities. Data on the amount of cargo handled were not available. About 730 vessels use the port each year. The major docking facilities at Amherstburg are those maintained by Brunner Mond Canada Ltd., manufacturers of calcium chloride and other chemical products. Ontario Hydro-Electric also receives large quantities of coal at Amherstburg each year.

Table IV-3. Traffic at Ecorse Port Facilities

Year	Tonnage* (Short Tons)		Vessel traffic					
	Inbound Receipts & Imports	Outbound Exports & Shipments	Inbound			Outbound		
			Steamers	Motor Vessels	Barges	Steamers	Motor Vessels	Barges
1944	690,906	36,545	330	2	104	330	2	106
1945	1,046,386	59,208	354	0	139	346	0	139
1946	839,885	58,281	310	23	83	310	23	83
1947	1,139,155	25,582	398	26	76	394	25	77
1948	1,107,896	66,329	666	3	57	665	3	56
1949	1,231,856	229,280	801	3	37	804	2	38
1950	1,599,613	303,416	757	13	100	758	11	99
1951	1,090,194	112,054	1,702	7	134	1,705	9	134
1952	1,161,670	166,691	1,806	9	150	1,807	9	150
1953	1,558,708	228,765	1,738	67	146	1,739	65	145
1954	2,526,741	259,996	1,078	16	201	1,080	18	203

*Does not include local traffic.

Source: U. S. Corps of Engineers

Table IV-4. Traffic at Wyandotte, Port Facilities

Year	Tonnage* (Short tons)		Vessel Traffic					
	Inbound Receipts & Imports	Outbound Exports & Shipments	Inbound			Outbound		
			Steamers	Motor Vessels	Barges	Steamers	Motor Vessels	Barges
1944	2,309,998	58,990	433	20	-	432	20	-
1945	2,144,444	55,952	425	19	0	425	19	0
1946	2,214,665	36,971	420	20	3	421	20	3
1947	2,433,642	31,487	520	10	7	520	10	7
1948	2,448,556	5,768	516	14	14	515	14	14
1949	2,280,410	34,986	685	16	5	685	16	5
1950	2,738,181	26,682	610	12	8	610	12	8
1951	2,915,108	30,412	536	16	15	537	16	5
1952	2,268,787	30,100	417	21	19	418	21	19
1953	2,544,778	9,446	483	14	8	483	14	8
1954	2,330,111	68,771	492	24	19	492	24	25

*Does not include local traffic.

Source: U. S. Corps of Engineers

Table IV-5. Traffic at Riverview and Trenton, Port Facilities

Year	Tonnage* (Short tons)		Vessel traffic					
	Inbound Receipts & Imports	Outbound Exports & Shipments	Inbound			Outbound		
			Steamers	Motor Vessels	Barges	Steamers	Motor Vessels	Barges
1944	369,680	180,152	112	12	136	112	12	136
1945	98,648	559,410	85	14	158	85	14	158
1946	346,349	175,177	96	42	63	96	42	63
1947	415,032	54,453	81	18	92	81	18	92
1948	605,174	51,018	106	30	107	106	30	107
1949	530,375	18,031	83	35	94	83	35	94
1950	1,160,121	1,687	0	248	200	0	247	200
1951	1,154,911	114,159	11	262	210	11	262	210
1952	1,139,056	167,002	5	311	234	5	311	234
1953	1,314,883	165,169	3	313	260	3	313	260
1954	1,639,205	140,532	3	213	149	3	213	149

*Does not include local traffic.

Source: U. S. Corps of Engineers.

Table IV-6. Traffic at Windsor and Walkerville, Port Vacilities

	1954	1955	1956 (to August 31)
Vessels			
Canadian	487	504	379
United States. .	298	305	185
Foreign	2	8	18
Cargo (Short tons)			
Coal	713,291	501,181	548,141
Other bulk [a] . .	2,718,239	808,757	473,388
Packaged. . . .	70,914	95,424	66,450

[a] Includes grains.

Source: National Revenue, Canada: Customs and Excise Houses of Windsor and Walkerville.

DETROIT RIVER TRAFFIC

Through and Port Traffic

The Detroit River has been called the busiest waterway in the world. During the past decade, an average of about 120,000,000 short tons of cargo per year have traversed the river, of which about 24,000,000 tons were handled at port facilities in the Detroit River area. An average of over 28,000 commercial vessels per year have passed through the river and used the ports along its shores. Over 1,000,000 passengers use the ports in an average year. During the period 1944-1954, through traffic has varied from a low of 79,900,000 short tons in 1954 to a high of 115,900,000 short tons in 1944. Port traffic during the same period varied from a low of 16,500,000 short tons in 1945 to a high of 26,600,000 short tons in 1953 (Table IV-7).

In past years, the principal cargoes carried on the Detroit River have been bulk cargoes--primarily iron ore, coal, grain, corn, limestone, oil, and gravel. Over 33,000,000 tons of coal passed through the Detroit River or stopped at its ports. More than 78,000,000 tons of iron ore, 13,000,000 tons of stone (mostly limestone), 2,000,000 tons of petroleum products, and almost 4,000,000 tons of corn and grain passed

Table IV-7. Detroit River Traffic

Year	Traffic of Ports					Through Traffic				
	Short Tons	Vessels and Trips			Passengers	Short Tons	Vessels and Trips			Passengers
		Steamships	Motor Vessels	Barges			Steamships	Motor Vessels	Barges	
1944	17,319,356	9,222	311	3,443	1,850,011	115,927,718	24,787	477	2,550	19,910
1945	16,532,853	8,858	262	1,949	1,804,098	110,512,162	23,099	498	1,838	9,608
1946	16,921,788	9,282	463	936	1,537,732	94,571,770	a	a	a	10,821
1947	19,071,576	10,686	511	927	1,345,584	108,368,586	24,424	670	1,192	1,240
1948	20,315,088	11,443	882	1,426	1,327,673	113,425,232	25,627	1,063	1,804	2,056
1949	18,673,721	12,863	920	1,242	1,163,717	89,790,565	24,362	1,223	1,515	405
1950	23,976,188	12,509	2,184	1,642	988,088	103,315,475	25,212	2,525	1,962	729
1951	24,331,744	13,552	1,915	1,968	920,659	107,185,800	25,221	2,106	2,176	15
1952	23,479,809	12,878	2,130	2,450	947,078	93,070,485	22,785	2,028	2,176	342
1953	26,560,928	13,772	2,226	2,513	1,077,145	114,168,482	13,772	2,226	2,513	432
1954	22,429,968	9,998	1,706	2,189	1,049,881	79,928,068	18,342	1,880	1,888	2,293

[a] Figures on through traffic for vessels not included in source materials for 1946.

Source: Annual Report of the Chief Engineer, Corps of Engineers, U. S. Army, 1944 to 1952.

through the river in 1953.

In addition to these and other bulk cargoes such as cement, sand, gypsum, salt, iron and steel scrap, pulp wood, and others, the river and its ports have handled an increasing amount of packaged cargoes. Automobiles, trucks, tractors, and other automotive equipment have constituted a significant proportion of the cargo shipped from the Detroit-Windsor area. In addition, chemicals, steel mill products, and paints and varnishes have been important cargoes since the end of World War II.

Ocean freighters have come up the lakes to the Detroit-Windsor area or through the Detroit River to the upper lakes' ports carrying over 70 classes of commodities ranging from liquors, wines, and sugar products to agricultural machinery and parts, glass and glass products, and tools and hardware. Overseas shipments to the Detroit area have included fish and dairy products, fruits, and spices. Leaving the area on ocean-going vessels, either for American or overseas ports, have been meats, animal oils, molasses and other sugar products, seeds, motor vehicles, hides and skins, zinc ore concentrates, and a wide variety of other commodities in 47 customs listings.

Ferry Traffic

Historically, a major user of the Detroit River has been the Detroit-Windsor ferry (Table IV-8). Regular ferry trips ceased several years ago and, at present, cross the river only when traffic warrants. No more than five ferries are now operating at irregular intervals around the clock. These are maintained by the Canadian National Railway, the Wabash Railway, and the Chesapeake and Ohio Railway. In 1956, only one of the ferries in use was coal-fired. Ferry traffic has diminished markedly since the opening of the New York Central tunnel from Windsor to Detroit.

Table IV-8. Detroit River Ferry Traffic

Year	Trips across the river	Freight in thousands of short tons	
		Eastbound to Windsor	Westbound to Detroit
1944	30,608	11,716	4,401
1945	27,305	9,696	4,339
1946	23,922	8,116	4,159
1947	20,350	8,382	4,440
1948	18,486	7,546	4,791
1949	18,218	6,642	4,048
1950	19,241	7,409	4,692
1951	21,484	8,239	5,751
1952	16,876	6,125	4,506

Source: Annual Reports of the Chief Engineer, U.S. Corps of Engineers, 1944 to 1952.

Registry of Vessels

The great majority of vessels using the Detroit River are of American registry, approximately 10 times as numerous as those of all other nations combined (Table IV-9). Canadian-British vessels are next most numerous. Vessels of other registry began to assume some importance about 1947. They are registered in France, West Germany, The British Commonwealth of Nations, Italy, North African nations, and Baltic nations. In 1950, the Port of Detroit handled 29,000 tons of overseas cargo; by 1953, this had increased to over 136,000 tons. By 1965, it is estimated that foreign cargo arriving at Detroit River ports will be over 1,000,000 tons per year.

Estimated Future Traffic -- The Effect of Opening the St. Lawrence Seaway

The expanding economy and increasing population of the United States and Canada, including Detroit River area, will surely result in at least a proportional increase in vessel traffic in the Detroit River. Consideration is given to these factors in the estimates appearing later in this section.

The development of the St. Lawrence Seaway promises not only an increase in overseas trade but greater traffic of ocean-going American vessels as well. Contracts for improvement of certain shipping channels in the Detroit River for Seaway purposes were let during the early autumn of 1956. Among other things, these call for deepening all major channels to a minimum depth of 27 feet. A flourishing world-wide shipping and commerce future seems assured for the Detroit-Windsor area.

Estimates vary concerning the impact of the St. Lawrence Seaway upon the Detroit-Windsor area. Surveys for the Corps of Engineers by the research firm of Knappen-Tippets-Abbett-Mc-

Table IV-9. Registry of Vessels Using Detroit River

(Data given as number of vessel trips)

Year	American			Canadian-British			Other		
	Steam-ships	Motor Vessels	Barges	Steam-ships	Motor Vessels	Barges	Steam-ships	Motor Vessels	Barges
1944	22,667	414	2,418	2,120	63	132	2	0	0
1945	20,957	362	1,712	2,142	136	126	0	0	0
1946[a]	-	-	-	-	-	-	-	-	-
1947	22,442	572	964	1,929	74	228	53	24	0
1948	23,090	871	1,507	2,417	112	297	120	80	0
1949	22,198	900	1,234	2,009	223	181	155	100	0
1950	23,020	2,249	1,657	2,280	178	305	212	98	0
1951	22,781	1,799	1,935	2,262	148	241	178	159	0
1952	20,550	1,668	2,029	2,085	180	147	150	180	0

[a] Figures not available.

Source: Annual Reports of the Chief Engineer, U. S. Corps of Engineers, 1944 to 1952.

Carthy have provided some basis for planning, and in 1955 the Detroit Metropolitan Area Regional Planning Commission prepared a report that set forth the projected port needs to meet the expected influx of commercial shipping that the Seaway would produce. It is estimated that the bulk cargo trade will be relatively unaffected by the Seaway for many years to come. With the possible exception of iron ore, bulk cargo expansions are likely to follow present trends. The Seaway, however, will make Labrador iron ore more accessible to the steel mills in the Lake Erie region and may reduce the amount of ore shipping down the lake waterway from northern Minnesota, Michigan, and Wisconsin.

A definite and immediate increase is forecast in foreign trade. By 1965, more than 1,000,000 tons of foreign general cargo are expected to come into the area. No precise estimate is even suggested concerning the increase in domestic trade that may result from industrial and commercial developments in the Great Lakes area as the lanes of ocean-going shipping penetrate westward. Cargo traffic of at least twice the 1952 volume is predicted for 1965 (Table IV-10). Although increases are expected in both heavy bulk cargo and domestic cargo such as automobiles and trucks, the greatest percentage increases are seen in general cargo, both domestic and foreign.

It is apparent that substantial increases in air pollution from vessels are to be expected in the next 10 years unless measures are taken to reduce emissions from individual vessels.

COMMUNITIES ON THE DETROIT RIVER

INTRODUCTION

Exploration of the Detroit-Windsor area by French missionaries and voyageurs commenced in the latter 17th Century. The first settlement of any permanence came in 1701 when the French dispatched a force under the command of Cadillac to establish a post on the Detroit River. This community, known originally as Fort Pontchartrain, developed into the City of Detroit.

Table IV-10. Estimated Cargo Loads at the Port of Detroit[a]

(In thousands of tons)

Year	Heavy Cargo (Iron, Steel, Scrap)	Domestic Auto and Trucks	Domestic & Foreign Misc. Cargo[b]
1952	684	457	42
1960	1,090	610	440-744[c]
1965	1,765	730	1,045-1915

[a] Table does not include newsprint and cargo handled by Ford Motor Company.

[b] Includes foreign export of automobiles and trucks.

Source: Detroit Metropolitan Area Regional Planning Commission.

The boundary between British Canada and the United States was stated in the Treaty of Paris of 1783 as a line running through the middle of the Great Lakes and the rivers of the Great Lakes waterway. With the pacification of neighboring Indian tribes and the creation of the Michigan Territory by Congress in 1805, development of the Detroit area was accelerated. Its pivotal location on the Great Lakes waterway initially supported Detroit's commercial and industrial development. Despite decreases in packaged freight and passenger traffic on the river with the expansion of the railroads in the latter part of the 19th Century, Detroit and Windsor continued to expand. The area became a lumbering, steel-producing, salt-mining, and chemical-producing center at different times throughout the latter part of the century.

The rapid growth of the area did not begin, however, until the present century and the advent of the automobile. Since 1914, the automobile industry has constituted the major industrial group in the Detroit-Windsor area. Today, more than 40 percent of all employees in the automobile industry are found in the Detroit area. The headquarters of the so-called "Big Three" -- General Motors, Ford, and Chrysler -- are located in Detroit and Dearborn. Windsor is the largest automobile producer in Canada, having plants of Ford, General Motors, and Chrysler.

The Second World War wrought far reaching consequences in the Detroit area. It caused both expansion and dispersion of the automobile industry throughout the area. Since 1945, there has been an extensive industrial development northeast of Detroit in Warren Township (became Warren City in 1956) and west of the city in Northville, Plymouth, Nankin, and Canton Townships.

The same period has also witnessed an amazing suburban residential expansion. The cities of Oak Park, Saint Clair Shores, East Detroit, Roseville, Madison Heights, Livonia, Garden City, Allen Park, Lincoln Park, and others have appeared as constantly growing population centers. The townships of Warren, Southfield, Redford, Dearborn, Taylor, Nankin, Romulus, and Plymouth have also experienced huge population increases as hundreds of new postwar residential subdivisions have been completed. Accessibility to the Great Lakes waterway has influenced the location of industrial plants in the area. This has been particularly true along the downriver areas of Ecorse, Wyandotte, and River Rouge and the navigable portion of the Rouge River into the vast Ford Rouge plant. Other factors influencing development of the area have been man-made, the most important being accessibility to railroads and highways and the availability and costs of land. In recent years, however, the motor companies have dispersed their plant locations throughout the area in a pattern that has the effect in part of enabling employees to live close to their places of employment.

POPULATION

The population of the study area in 1955 was about 3,360,000, with approximately 220,000 of this number on the Canadian side of the Detroit River. The City of Detroit had a population of about 1,900,000 in 1955, while estimates for Wayne County were 2,693,000. The southern townships and communities of Macomb and Oakland Counties had an estimated population of 188,340 and 263,450 respectively. By 1960, it is expected that Detroit will contain nearly 2,000,000 of the estimated 3,500,000 people living in the area (Figure IV-5).

More significant for the future than the size of Detroit, however, is the growth rate of the area outside the city. Recently the Detroit Metropolitan Area Regional Planning Commission reported that, in the metropolitan area, population of areas outside of Detroit would soon be larger than in the city. It should be noted that the so-called metropolitan area of Detroit encompasses a larger region than does the study area of this report.

Although, in some instances, the very small towns have experienced large percentage increases, these have not constituted significant numerical increases. The larger suburban communities adjacent to Detroit, however, have experienced both significant percentage and numerical increases, particularly Dearborn, Livonia, East Detroit, Roseville, St. Clair Shores, Warren Township (now City), Oak Park, Royal Oak, and Southfield Township (Table IV-11).

The percentage increase of population in the Detroit Standard Metropolitan Area (U.S. Census) was the third highest of the eight largest cities in the United States for the decade 1940 to 1950. In terms of numbers of additional people, Detroit had the fifth greatest increase (Table IV-12). It is apparent, therefore, that unless action is taken to reduce pollution emissions from the various sources, air pollution levels can be expected to increase along the same general lines as the population.

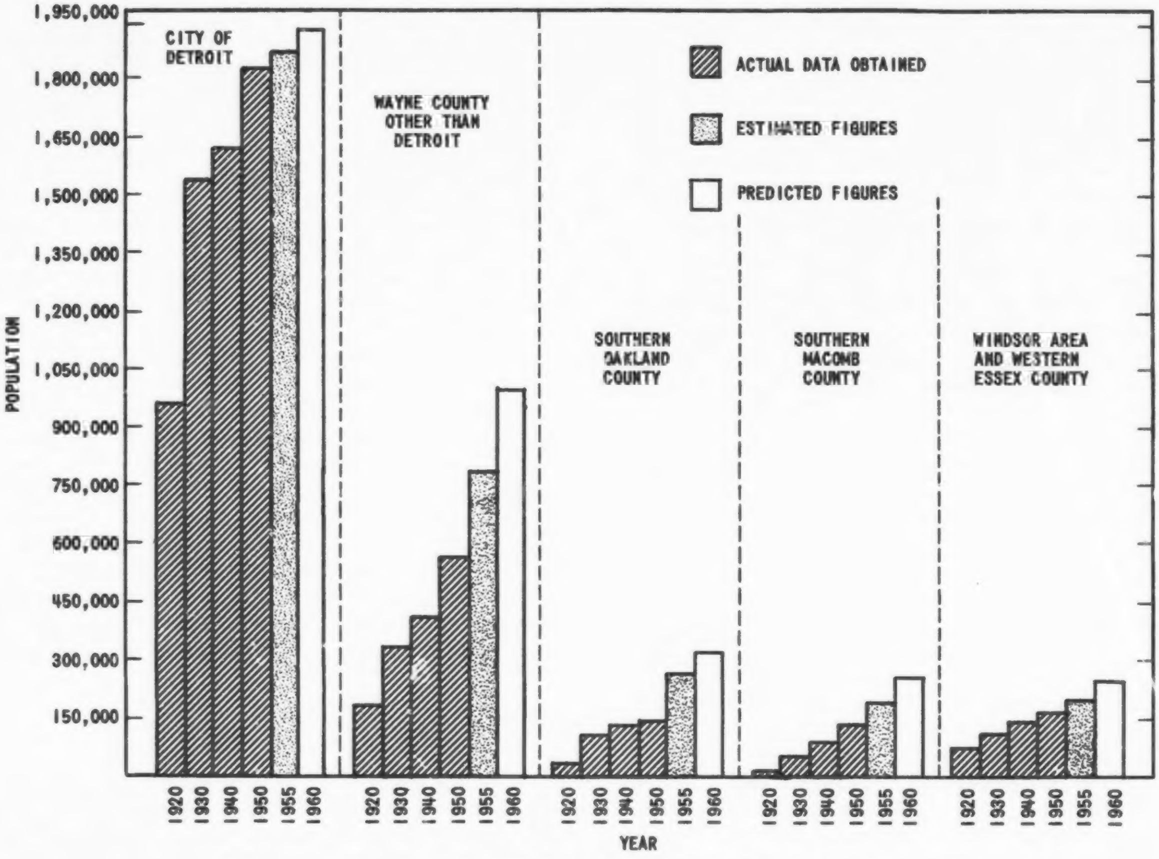


Figure IV-5. Detroit-Windsor Study Area Population Growth

Table IV-11. Population Growth of Communities in the Detroit-Windsor Area

City, Township Village or County	1930	1940	1950	1955	1960 (Est.)
Wayne County	1,888,946	2,015,623	2,435,235	2,693,000	2,904,000
Dearborn City	50,358	63,584	94,994	113,500	134,000
Dearborn Township	3,738	11,087	25,807	29,600	41,000
Inkster Village	2,393	3,035	5,572	31,800	40,000
Detroit City	1,568,662	1,623,452	1,849,568	1,902,000	1,920,000
Ecorse City	12,716	13,209	17,948	18,200	18,800
Ecorse Township	18,025	18,571	22,711	19,400	28,000
Allen Park Village	944	3,487	12,329	30,400	43,300
Garden City	2,081	4,096	9,012	22,100	35,500
Grosse Point Park	11,174	12,646	13,075	14,700	16,000
Grosse Point Woods	961	2,805	10,381	16,000	21,000
Grosse Point Farms	3,533	7,217	9,410	11,800	14,000
Hamtramck City	56,268	49,839	43,355	40,800	39,500
Highland Park City	52,959	50,810	46,393	44,600	43,500
Lincoln Park City	12,336	15,236	29,310	43,900	50,000
Livonia City	3,192	8,728	17,534	35,400	55,000
Melvindale City	4,053	4,764	9,483	11,700	14,000
Trenton Village	4,022	5,284	6,222	10,100	15,000
Nankin Township	17,357	24,070	50,972	33,700	45,000
Wayne Village	3,423	4,223	9,409	13,400	16,000
Redford Township	3,834	6,867	18,940	50,000	68,000
River Rouge	17,314	17,008	20,549	20,800	22,000
Romulus Township	2,979	6,880	12,311	14,190	16,000
Taylor Township	2,102	8,862	18,848	28,000	42,000
Wyandotte City	28,368	30,618	36,846	41,300	43,000
16 Others (Total)	45,603	53,963	70,943	73,637	92,900
Macomb County	77,146	107,638	184,961	280,000	371,000
East Detroit City	5,955	8,584	21,461	34,700	40,000
Roseville	6,836	9,023	15,816	34,700	46,000
St. Clair Shores	6,745	10,405	19,823	46,600	65,000
Warren Township	14,269	22,126	42,653	57,000	78,000
4 Others (Total)	11,468	15,031	28,180	15,340	20,500
Oakland County	211,251	254,068	396,001	542,000	685,000
Berkley	5,571	6,406	17,931	21,800	23,500
Birmingham City	9,539	11,196	15,467	22,400	27,800
Ferndale City	20,855	22,523	29,675	32,000	33,000
Hazel Park City	-	-	17,770	23,400	25,800
Oak Park City	1,079	1,169	5,267	27,200	36,500
Royal Oak City	22,904	25,087	46,898	65,500	80,000
Royal Oak Township	26,277	24,958	20,966	11,100	11,000
Southfield Township	3,174	8,486	18,499	27,900	42,000
Clawson	-	-	5,196	10,300	14,600
3 Others (Total)	4,667	6,377	10,011	13,450	16,200
		1931	1941	1951	
Essex County, Ontario		159,780	174,238	217,150	
Sandwich West Township		2,783	4,735	10,406	
Sandwich East Township		5,421	8,571	14,966	
Windsor		63,108	105,311	120,049	
15 Others (Total)		25,426	27,213	38,470	

Table IV-12. Comparative Population Statistics for Leading Metropolitan Areas

Area	1940 Population	Increase-- 1930-1940		1950 Population	Increase-- 1940-1950	
		Number	Percent		Number	Percent
New York	11,690,520	1,600,096	7.2	12,911,994	1,221,474	10.7
Chicago	4,499,126	134,371	3.1	5,495,364	998,238	13.9
Los Angeles	2,904,596	586,070	25.3	4,367,911	1,463,315	49.8
Philadelphia	3,199,637	352,489	1.8	3,671,048	472,411	14.7
Detroit	2,377,329	272,433	9.1	3,016,197	638,868	26.9
Pittsburgh	1,994,060	40,392	2.1	2,213,236	219,176	6.3
St. Louis	1,367,977	77,461	5.8	1,681,281	313,304	17.5
San Francisco . . .	1,428,525	138,431	10.7	2,240,767	812,239	53.3

Source: 16th and 17th Decennial Census of the U. S.

POPULATION DENSITY

The population density of the Detroit Standard Metropolitan Area is 1504 people per square mile, third highest of the nine leading metropolitan areas in the United States (Table IV-13). Population density in Essex County, Ontario is 307 persons per square mile. In the City of Windsor, this figure is 8078 and in the City of Detroit, 11,200. This relatively high population density would indicate that, in general, pollutants emitted to the atmosphere by activities of the people will be dispersed in a smaller volume of air than in cities of lower population density, other factors being equal.

Table IV-13. Population Densities for Leading Metropolitan Areas, 1950

Area	Density (Persons per square mile)
Chicago	1,476
Detroit	1,504
New York	2,929
Philadelphia	1,019
Pittsburgh	718
Los Angeles	879
Cleveland	2,130
St. Louis	649
San Francisco-Oakland . . .	592
Essex County, Ontario (1951)	307

It can be seen (Figure IV-6) that substantial numbers of poeple live in areas close to both sides of the Detroit River. They would more likely be adversely affected by pollution emission from vessels plying the river than those living farther away.

LAND USE AND DEVELOPMENT

Nearly every community within the study area has a zoning ordinance. In addition, many have master plans and central planning agencies. Unfortunately, the City of Detroit did not adopt either zoning ordinance or a master plan until the major features of the city had been well established. The one provision of the present Detroit zoning ordinance that merits particular note is that which prohibits residential land uses in industrial districts. Among the other major communities in the study area only Dearborn has a similar zoning provision. There still re-

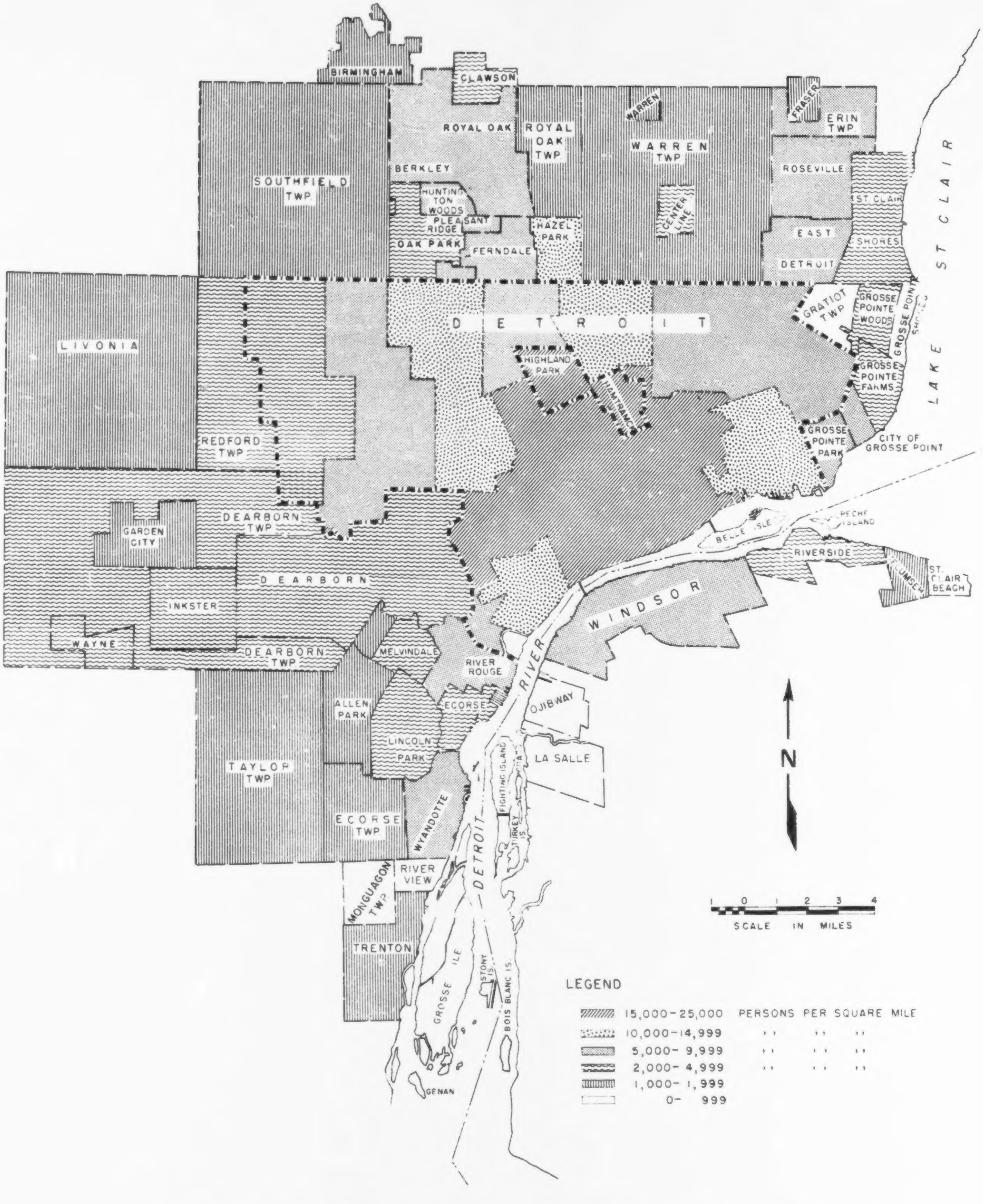

BIRMINGHAM
CLAWSON
ROYAL OAK
ROYAL OAK TWP.
WARREN
FRASER
ERIN TWP.
WARREN TWP.
SOUTHFIELD TWP.
BERKLEY
HUNTINGTON WOODS
PLEASANT RIDGE
OAK PARK
FERNDALE
HAZEL PARK
CENTER LINE
ROSEVILLE
ST. CLAIR
EAST DETROIT
SHORES
LAKE ST. CLAIR
LIVONIA
DETROIT
GRATIOT TWP.
GROSSE POINTE WOODS
GROSSE POINTE SHORES
HIGHLAND PARK
HAMTRAMCK
GROSSE POINTE FARMS
REDFORD TWP.
GROSSE POINTE PARK
CITY OF GROSSE POINT
PECHE ISLAND
BELLE ISLE
DEARBORN TWP.
GARDEN CITY
RIVERSIDE
TECUMSEH
ST. CLAIR BEACH
DEARBORN
INKSTER
WINDSOR
WAYNE
DEARBORN TWP.
MELVINDALE
RIVER ROUGE
RIVER
OJIBWAY
ALLEN PARK
ECORSE
LINCOLN PARK
LA SALLE
N
TAYLOR TWP.
FIGHTING ISLAND
TURKEY IS.
ECORSE TWP.
WYANDOTTE
DETROIT
MONGUAGON TWP.
RIVER VIEW
1 0 1 2 3 4
SCALE IN MILES
TRENTON
GROSSE ILE
STONY IS.
BOIS BLANC IS.
GENAN
LEGEND
▨ 15,000-25,000 PERSONS PER SQUARE MILE
▨ 10,000-14,999 " " "
▨ 5,000- 9,999 " " "
▨ 2,000- 4,999 " " "
▨ 1,000- 1,999
☐ 0- 999

Figure IV-6. Population Density in the Study Area - (1955 Estimates)

main significant parcels of residential land use within the industrial districts of Detroit, although redevelopment plans call for eventual discontinuation of such use.

Other communities within the area have been more fortunate in having a historical coincidence between zoning and community growth. The regional land use studies and the regional master planning undertaken by the Regional Planning Commission have provided the impetus for many communities in the area to engage in community planning and to use zoning ordinances as an enforcement device.

Fifty-six percent of the land in Detroit is developed for industrial, commercial, residential, public, and semipublic purposes (excluding roads, streets, and undeveloped areas). Over 14 percent of this developed area is presently used for industrial purposes and is largely in the 27 industrial corridors located within the city (Figure IV-7). Many residential areas are in close proximity to industrial areas from which heavy pollution emissions may occur, thus exposing the residential areas to possible relatively high pollution levels.

In Windsor, residential areas are also located close to industrial areas (Figure IV-8) and are faced with the same air pollution problems as Detroit.

On both sides of the river, residential and commercial areas are located close to the river. Recreational areas are located along the river and on islands in the river. These are the types of areas most likely to be adversely affected by air pollution.

As might be expected, the highly developed and populated areas are experiencing no basic changes in land use practices since very little undeveloped land has been available in these areas for purposes of new building. For the other areas, there have been changes in the last few years, but these have been primarily increases in residential and commercial uses of vacant land. The industrial expansions, particularly in the areas immediately northeast, west, and southwest of Detroit, have not drastically altered the proportions of various land uses since 1949.

Future development of the study area is likely to follow established expansion patterns with areas nearby the principal cities being developed most rapidly. No great concentration of any particular type of land use is foreseen for any certain portion of the area. Possible exceptions are the areas adjacent to and northwest of Detroit which may be largely residential, and downriver areas near the river which may experience relatively great industrial expansion. The City of Detroit and other areas fronting the river are almost fully developed at the present time, although within the City of Detroit an ambitious redevelopment program has been underway for several years. This program was directed initially at the redevelopment and rehabilitation of the inner core of the city, lying between the river and Grand Boulevard. The program would eliminate much of the high density and substandard residential housing with replacement by some high desnity, middle and high income housing and some low-rent public housing. Several long-range civic projects such as Wayne State University Cultural Center, the Medical Campus, and the Civic Center are also included in the program. The Civic Center project, presently going forward, is located very near the river.

INDUSTRIALIZATION

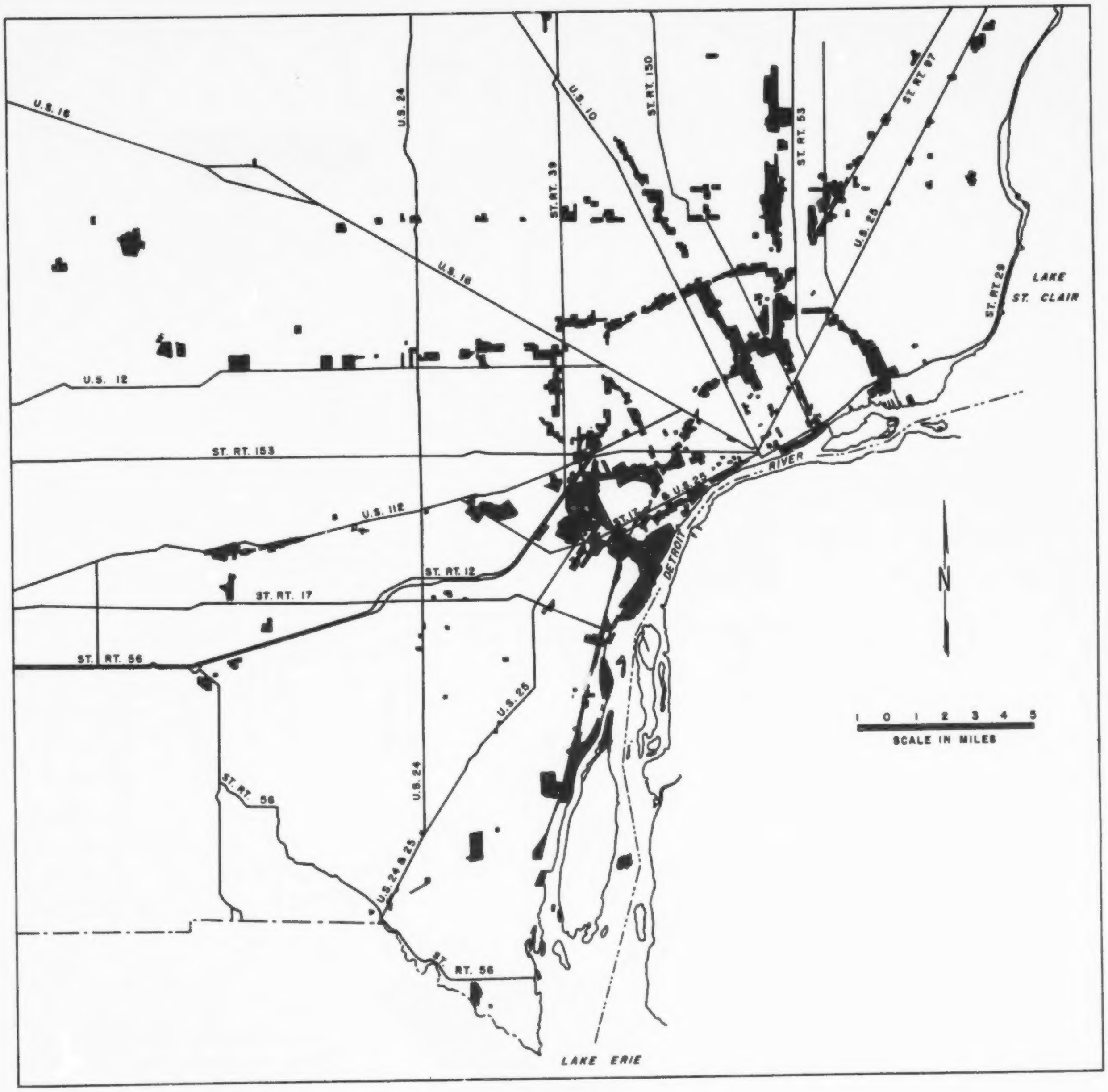
Heaviest industrialization has been along the Detroit and Rouge Rivers where accessibility of water transportation has been a strategic factor. The major railroads interlaced throughout the area provide similar impetus for industrial development.

There are about 6400 industrial establishments in the study area, employing about 752,000 persons. The vast majority of these are in Wayne County (Table IV-14).

Table IV-14. Industrial Plants and Employment in the Study Area

Area	Number of plants	Number of Employees
Wayne County	4,922	659,000
Oakland County	576	20,000
Macomb County	456	43,000
Windsor Area	455	30,000
Total	6,409	752,000

Figures for the Detroit area are taken from report of the Detroit Metropolitan Area Regional Planning Commission on Manufacturing Employment in the Detroit Region, December 1954. Windsor area figures taken from general estimates by Windsor Chamber of Commerce, in the Greater Windsor Directory of Industries, 1956.


U.S. 16
U.S. 24
U.S. 10
ST. RT. 150
ST. RT. 53
ST. RT. 97
ST. RT. 39
U.S. 16
U.S. 25
ST. RT. 29
LAKE
ST. CLAIR
U.S. 12
ST. RT. 153
U.S. 112
U.S. 25
RIVER
ST. 17
DETROIT
ST. RT. 12
ST. RT. 17
ST. RT. 56
N
1 0 1 2 3 4 5
SCALE IN MILES
U.S. 25
ST. RT. 56
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LAKE ERIE

Figure IV-7. Industrial and Utility Land Use in United States Part of Study Area - 1952

Reproduced from best available copy.

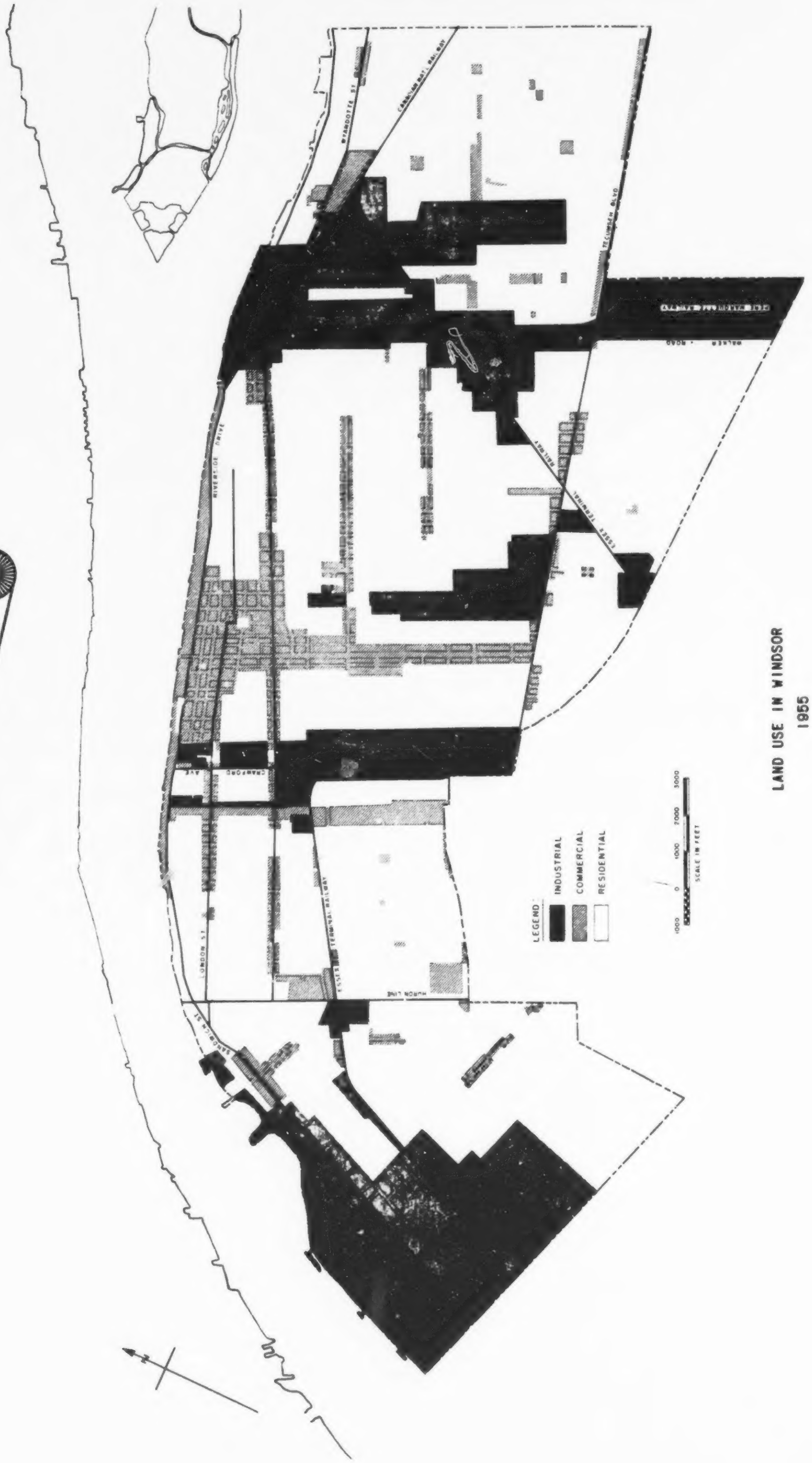

LAND USE IN WINDSOR
1955
LEGEND:
INDUSTRIAL
COMMERCIAL
RESIDENTIAL
1000 0 1000 2000 3000
SCALE IN FEET
WYANDOTTE ST.
CANADIAN PAC. RAILWAY
TECUMSEH BLVD
WALKER ROAD
ESSEX TERMINAL RAILWAY
RIVERSIDE DRIVE
CRAWFORD
AVE
LONDON ST.
HURON LINE
SANDWICH ST.

Figure IV-8. Land use in Windsor - 1955

Table IV-15. Number of Plants and Employees in Major Industrial Groups in Detroit Metropolitan Area, 1953

Industrial group	Wayne County		Oakland County[a]		Macomb County[a]	
	Number of establishments	Total employees	Number of establishments	Total employees	Number of establishments	Total employees
Mining						
crude petroleum and natural gas: nonmetallic mining	31	507	...	...	...	...
Manufacturing						
Ordnance and accessories	19	11,292	...	...	...	...
Food and kindred products	...	...	27	588	15	123
Meat products	83	3,728	...	...	...	...
Dairy products	33	882	...	...	...	...
Canning, preserving and freezing	21	354	...	...	...	...
Grain-mill products	11	181	...	...	...	...
Bakery products	105	7,058	...	...	...	...
Beverage industries	46	5,240	...	...	...	...
Textile mill products	28	1,682	...	...	...	...
Apparel and other fabric products	144	4,758	...	...	...	...
Lumber and wood products	117	2,143	40	676	15	162
Furniture and fixtures manufacture	118	3,321	...	...	...	...
Paper and allied products	51	5,325	4	412	...	...
Chemicals and allied products	216	18,202	21	633	3	82
Products of petroleum and coal	28	3,099	...	...	...	...
Rubber products	17	8,234	3	1,100	...	...
Leather and leather goods	23	1,176	...	...	...	...
Stone, clay and glass products	159	8,620	25	280	11	725
Primary metal industries	...	...	...	...	13	2,107
Blast furnaces and steel mills	9	18,785	...	...	...	...
Iron and steel foundries	37	12,667	4	1,383	...	...
Nonferrous industries	96	8,739	7	288	...	...
Fabricated metal products	...	...	147	4,973	104	4,996
Cutlery, hard tools and hardware	70	11,237	...	...	...	...
Heating and plumbing equipment	29	1,607	...	...	...	...
Fabricated structural metal products	150	10,115	...	...	...	...
Metal stamping, coating and engraving	273	36,727	...	...	...	...
Machinery (except electrical)	1,237	83,149	332	9,728	213	6,203
Electrical machinery and equipment	92	5,874	17	275	8	243
Transportation equipment	...	...	...	...	...	...
Motor vehicle and equipment	157	273,532	22	32,711	21	16,847
Aircraft and parts	24	11,865	10	1,089	3	360
Ship and boat building and repairing	14	1,429	...	...	...	...
Instruments and related products	71	1,460	...	...	...	...
Miscellaneous manufacturing industries	303	6,596	48	3,005	37	785
Public Utilities						
Local railways and bus lines	6	501	...	...	...	...
Trucking and warehousing	785	18,752	77	1,657	...	...
Trucking, local and long distance	610	16,000	60	1,485	...	...
Taxicabs	479	5,090	25	258	...	...
Air transportation	19	913	...	...	...	...
Utilities and sanitary services	36	14,941	14	757	...	...
Gasoline service stations	1,790	6,516	359	1,096	...	...
Laundry and other services	308	7,071	18	251	10	95
Cleaning and dyeing plants	223	3,896	28	384	10	126

Source: U.S. Old Age and Survivors Insurance Bureau, County Business Patterns, U.S. Government Printing Office, 1955, Part 4.

[a] Entire county data given which includes a greater area than the study area.

Only four or five plants in the entire Windsor area employ more than 1,000 persons. Of the more than 450 industries located in the Windsor area, nearly 425 are found in Windsor proper or its immediate environs. There are no plants with more than 1,000 employees outside of Windsor proper. Four plants have between 500 and 999 employees; 14 establishments employ between 250 and 499 persons; 24 plants have between 100 and 249 employees, and over 400 have fewer than 100 employees. The large industries are found entirely within the area designated as industrial in Figure IV-8. No data were available concerning the specific kinds of industrial establishments in the Canadian portion of the study area, but the nature of Canadian industry is generally the same as that in the United States portion of the area.

In the United States portion of the study area, motor vehicle manufacturing provides employment for about 40 percent of all industrial workers. Other large employing industries are ordnance, chemicals, primary metals, fabricated metals, machinery, and public utilities (Table IV-15). A great number of these industrial activities often emit substantial quantities of pollutants to the atmosphere.

No major trend toward a different type of industrial complex has been predicted for the area, although some slight changes in the relative importance of various industries are expected. Industrial activity is expected to expand at a rate approximating the population growth and, therefore, an increase in industrial activity of about 10 percent would be estimated in the next five years. This growth would tend to indicate that air pollution emissions from industrial activity will similarly increase unless emissions from individual sources are reduced.

Chapter V

CLIMATOLOGY OF THE DETROIT-WINDSOR AREA

INTRODUCTION

The climatology of the Detroit-Windsor area is determined primarily by its location with respect to features of the hemispheric flow pattern of the atmosphere. The area lies between 42 and 43 degrees north latitude, in the mid-latitude belt of a general west-to-east flow of air during all seasons of the year. The traveling high and low pressure systems moving with this westerly flow are associated with frequent surges of fresh air masses in the form of a succession of cold frontal passages at all seasons. The average number of days between significant cold frontal passages is 4 to 5. The maximum monthly average interval between such passages is 5 to 6 days and occurs in August (Table V-1).

The area is well within the continental North American land mass, at approximately 83 degrees west longitude, so that the climate is basically a continental type, with warm summers and cold winters. The waters of the Great Lakes exert a modifying influence, however, particularly in the winter months, since these large water masses have a much greater thermal capacity than the surrounding land surfaces. Thus, extremes of water temperature lag behind extremes of air temperature (Figure V-1). A listing of monthly temperatures is given in Tables V-2 and V-3.

It is unlikely that the water in the middle of any of the larger lakes freezes over during the winter, although ice generally does form for a portion of the cold season in protected areas and in shallow bays and estuaries in most of the lakes. It is this ice formation which determines the opening and closing of the navigation season on the Great Lakes (Table V-4).

Within the region surrounding the Detroit-Windsor area (Figure V-2), there are small climatic differences due to differences in the degree of urbanization, the proximity of bodies of water, and to a slight extent, the topography. A general tendency can be noted for stations in the lee of Lake Huron (Forest, London, and St. Thomas) or Lake Erie (Clear Creek, St. Thomas, and Simcoe) to be relatively colder in the spring and early summer and relatively warmer in the late fall and early winter. The heating influence of the urban area is shown by the fact that Detroit City Airport reports higher average temperatures than almost all other stations in the area throughout the year. The only other stations reporting higher average temperatures are Monroe, the southernmost station, and Grosse Point Farms, which is probably influenced by the Detroit urban area and by Lake St. Clair.

Temperature differences between urban and nonurban and land and lake areas will produce modifications of the prevailing air flow patterns on some days such that the air will tend to flow from the colder toward the warmer area.(16) This tendency will increase as the thermal contrast between adjacent areas increases and as the strength of the prevailing air flow decreases.

SEASONAL VARIATION OF THE GENERAL AND REGIONAL ATMOSPHERIC CIRCULATION

The seasonal variation of the circulation is basically an oscillation between summer and winter conditions. In winter, the zone of greatest temperature contrast between polar and subtropical air masses is generally south of the Detroit River area. The west winds throughout most of the atmosphere below the tropopause, which are associated with the meridional temperature gradient, are at a maximum, and the belt of strongest westerly winds is well south of the area at this longitude.(119) The Detroit-Windsor area is, therefore, within the polar air masses most of the time, with reinforcing surges of polar air sweeping across the area from the

Table V-1. Frequency of Significant Cold Frontal Passages - Detroit[a]

Year	Month												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1951	5	7	7	7	6	5	7	7	9	8	8	8	84
1952	8	5	2	4	6	8	8	8	6	12	11	7	85
1953	7	7	8	6	6	9	6	4	9	5	7	8	82
1954	6	8	6	8	5	7	5	5	10	6	7	7	80
1955	7	7	6	8	7	3	6	4	7	6	9	7	77
Total	33	34	29	33	30	32	32	28	41	37	42	37	408
Days per front	4.7	4.1	5.3	4.5	5.2	4.7	4.8	5.5	3.7	4.2	3.6	4.2	4.5

[a] From weather maps analyzed by U.S. Weather Bureau Office in Cincinnati, Ohio

Table V-2. Average Surface Water Temperature of the Great Lakes
(Data in parentheses are estimated)

Month	Superior	Michigan	Huron	Erie	Ontario
January	(34)	(37)	(35)	(33)	37
February	(34)	(35)	(34)	(33)	35
March	(33)	(36)	(34)	(34)	35
April	(34)	(37)	(35)	(38)	37
May	35	41	39	50	42
June	39	51	48	63	54
July	44	61	64	70	67
August	55	69	68	73	69
September	54	65	61	67	65
October	48	54	54	59	55
November	42	46	45	49	49
December	(38)	(38)	(38)	(39)	39

Table V-3. Monthly Mean Temperatures for Selected Climatological Stations 1951 to 1955(91,118)

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Chatham	27.3	29.1	34.7	47.7	58.3	69.0	73.6	71.0	64.0	53.4	40.0	30.4	49.8
Forest	24.6	27.1	32.6	46.5	54.9	66.0	71.1	69.0	61.4	51.6	37.6	28.3	47.6
Harrow	27.7	29.6	35.3	48.1	58.3	69.5	73.7	71.3	64.4	53.5	39.5	30.4	50.1
Leamington	27.5	28.8	34.3	46.9	57.2	68.1	73.0	71.0	64.5	53.4	39.4	29.8	49.5
Simcoe	24.4	26.2	32.4	45.6	54.4	65.6	70.2	66.9	59.7	49.9	37.7	28.2	46.8
St. Thomas	25.0	26.5	32.3	46.1	54.9	65.4	70.2	68.2	60.3	50.0	37.8	28.3	47.1
Woodslee	26.5	28.8	34.4	47.8	57.3	68.1	72.6	70.3	62.7	52.0	38.4	29.0	49.0
Clear Creek	26.1	27.2	32.2	44.5	53.0	64.1	70.2	67.8	61.0	51.1	39.0	30.6	47.2
London	23.8	26.1	31.5	45.8	54.9	65.8	70.8	68.3	60.2	50.0	36.9	27.0	46.7
Windsor	27.2	29.1	34.8	48.0	58.0	69.2	73.7	71.2	63.9	52.8	39.1	29.8	49.7
Detroit City Airport	27.8	30.2	35.6	49.0	58.7	70.2	74.7	72.3	64.6	53.9	39.9	30.5	50.6
Grosse Point Farms	28.6	30.6	35.8	49.3	59.0	70.3	74.7	72.0	65.4	54.8	41.0	31.2	51.1
Monroe	29.2	31.4	36.8	49.6	59.6	70.8	74.8	72.0	65.6	55.1	40.8	31.2	51.4
Mt. Clemens	26.7	29.0	34.2	47.8	57.8	69.2	73.9	71.3	63.5	52.9	39.1	29.7	49.6
Pontiac	26.1	28.3	34.5	48.5	58.5	69.2	73.7	71.6	63.9	53.4	38.7	28.6	49.6
Adrian	27.1	29.9	35.6	48.7	58.8	69.4	73.5	71.0	63.0	52.3	38.3	29.3	49.8
Labeer	24.7	27.5	33.3	47.5	56.6	66.5	71.7	69.0	61.6	51.7	38.1	27.5	48.0

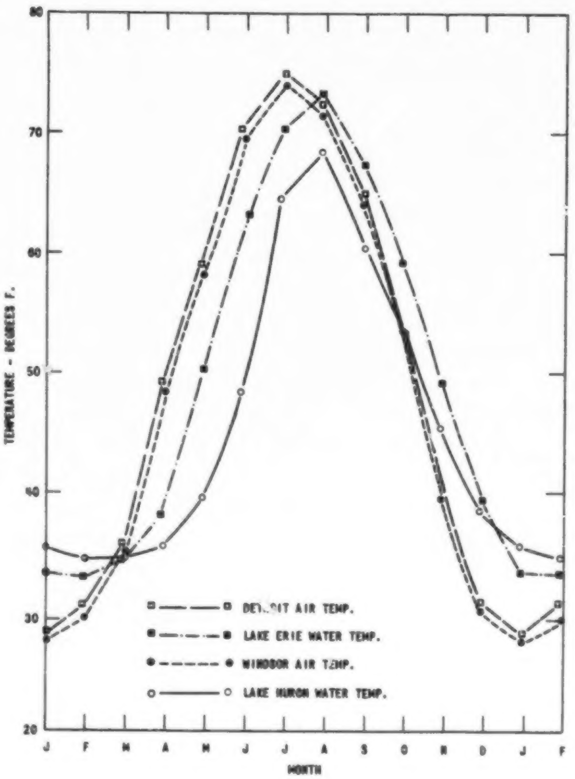


Figure V-1. Monthly Average Air and Water Temperatures

northwest quadrant. This trajectory carries the air across at least one of the three larger lakes before it arrives in the area of interest, so that this air acquires heat and moisture by its passage over the open lake waters. Cloudiness and snow showers associated with the unstable stratification represent the prevailing type of weather in the winter months (Figures V-3 and V-4).

Wind direction is quite variable during all seasons of the year because of the succession of traveling pressure systems and associated air masses. During the winter season, the winds are most often from a westerly direction, from south of west in December and tending toward more north of west by March. Wind speeds average well over 10 mph in the colder season of the year at the Detroit(117) and Windsor(89) airports (Figure V-5). The actual difference of winds at these stations is very likely not as indicated by the graphs, because of a difference in the periods of record represented and particularly of instrumental response. This latter difference is emphasized by the much higher frequency of calm conditions reported at the Windsor site and by the seasonal change of wind speed difference for particular directions (Table V-5 and V-6).

Table V-4. Navigation Season for Interlake Shipping on the Detroit River

(Data Compiled by U. S. Weather Bureau, Detroit, Michigan)

Year	Date of -		
	Opening[a]	Closing[a]	First floating ice
1930	Mar. 20	Dec. 15	-
1931	Mar. 17	Dec. 15	-
1932	Mar. 1	Dec. 27	-
1933	Apr. 4	Dec. 27	-
1934	Mar. 28	Dec. 15	-
1935	Mar. 31	Dec. 16	-
1936	Mar. 19	Dec. 15	-
1937	Mar. 1	Dec. 15	-
1938	Mar. 13	Dec. 15	-
1939	Apr. 16	Dec. 15	-
1940	Apr. 16	Dec. 15	-
1941	Apr. 1	Dec. 14	-
1942	Mar. 25	Dec. 19	-
1943	Apr. 5	Dec. 19	-
1944	Mar. 22	Dec. 15	Dec. 15
1945	Apr. 1	Dec. 15	Dec. 13
1946	Mar. 26	Dec. 15	Dec. 18
1947	Mar. 27	Dec. 18	Dec. 9
1948	Mar. 19	Dec. 12	Dec. 18
1949	Mar. 16	Dec. 19	Dec. 9
1950	Mar. 14	Dec. 15	Dec. 6
1951	Mar. 3	Dec. 15	Dec. 15
1952	Mar. 12	Dec. 15	Dec. 28
1953	Mar. 4	Dec. 15	Dec. 23
1954	Mar. 16	Dec. 11	Dec. 20
1955	Mar. 6	Dec. 15	Dec. 12
1956	Mar. 17	Dec. 31	Dec. 14

[a] For entire period of record since 1872, earliest opening date was March 1, several years; latest opening date April 19, in 1881.

In the summer months, on the other hand, there are no appreciable regions where cold air

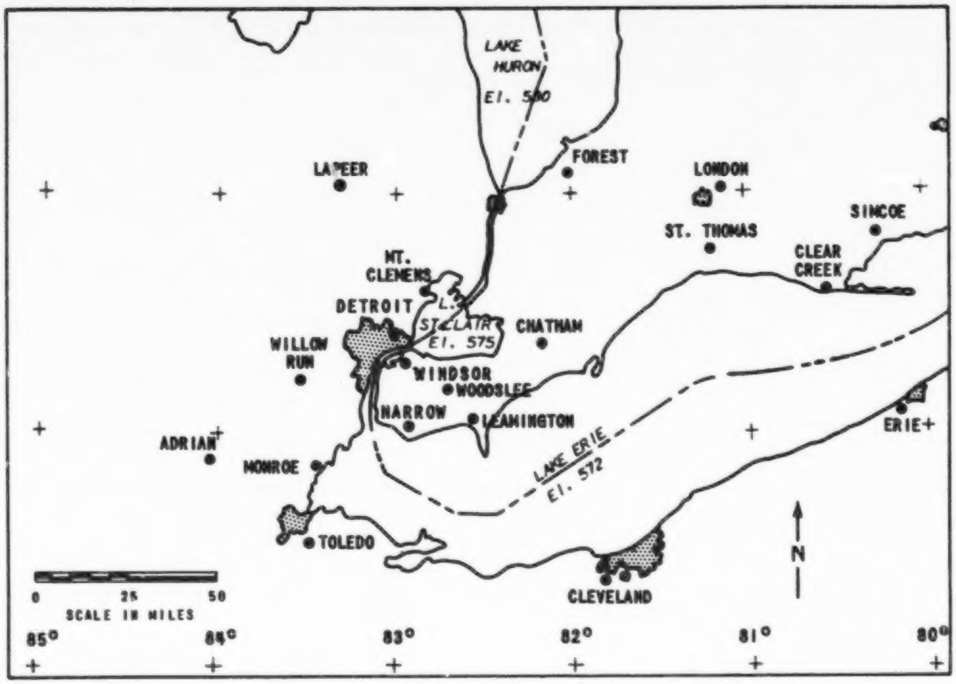

LAKE HURON
El. 580
LAPEER
FOREST
LONDON
SINCOE
ST. THOMAS
CLEAR CREEK
MT. CLEMENS
DETROIT
L. ST. CLAIR
El. 575
CHATHAM
WILLOW RUN
WINDSOR
WOODSLEE
NARROW
LEAMINGTON
ADRIAN
MONROE
LAKE ERIE
El. 572
ERIE
TOLEDO
CLEVELAND
N
0
25
50
SCALE IN MILES
85°
84°
83°
82°
81°
80°

Figure V-2. Climatological Stations in the Detroit River Area and Surrounding Region

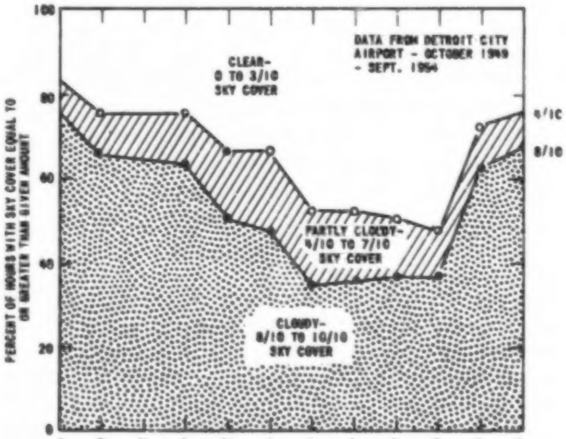


Figure V-3. Relative Hourly Frequency of Sky Cover Amounts

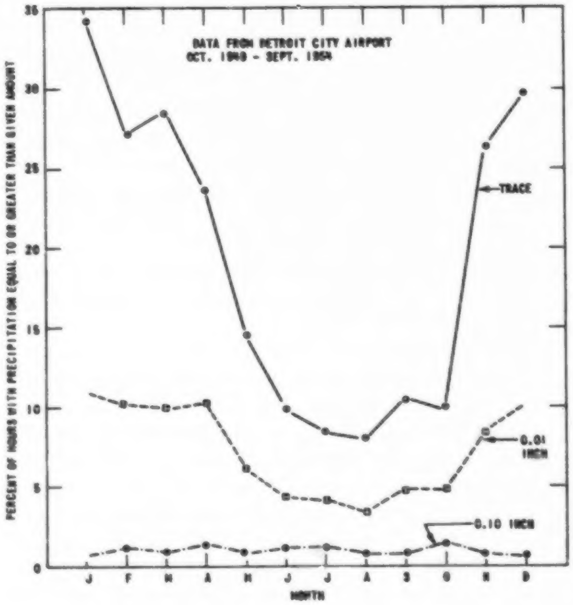


Figure V-4. Relative Hourly Frequency of Precipitation

Table V-5. Percent Frequency of Wind Directions and Average Wind Speeds
Detroit City Airport, October 1949 to September 1954

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Frequency of Occurrence, percent												
N	13	12	12	12	15	12	14	18	11	14	11	6
NE	7	8	6	9	12	6	8	9	6	8	4	4
E	6	9	16	14	15	12	10	10	9	8	4	6
SE	8	8	10	8	9	10	9	8	7	6	5	7
S	15	11	10	9	13	16	15	15	17	19	16	15
SW	16	15	10	12	8	13	13	10	15	16	22	23
W	14	18	16	19	14	15	14	13	17	13	17	22
NW	19	19	21	17	13	13	15	14	16	14	20	16
Calm	1	1	-	1	1	2	2	2	1	1	1	-
Average wind speed, by directions, miles per hour												
N	9.7	9.3	9.7	9.8	8.6	8.8	7.6	7.7	7.8	8.4	9.8	7.4
NE	7.9	9.7	8.3	9.1	7.8	7.1	6.3	6.8	6.7	6.9	8.2	6.8
E	7.3	8.2	8.6	8.8	7.7	7.1	6.4	6.5	6.8	7.0	8.0	7.3
SE	8.5	8.9	8.5	8.6	7.6	7.3	6.6	6.2	6.5	6.5	7.9	9.0
S	9.9	10.2	9.5	9.6	8.7	8.5	7.8	7.3	8.1	8.2	10.1	9.6
SW	13.3	13.2	13.8	13.4	11.4	10.4	9.9	8.2	10.2	10.9	12.8	13.8
W	13.7	13.5	15.4	13.7	12.6	12.0	9.7	9.0	11.1	10.2	12.7	13.0
NW	13.1	12.3	14.0	12.9	11.3	11.3	9.3	9.5	10.9	11.1	12.8	12.5
Average wind speed, miles per hour												
	11.0	11.1	11.5	11.1	9.3	9.2	8.0	7.6	8.9	8.9	11.3	11.3

masses can develop except over the cold or ice-covered northern water bodies, the nearest of which is Hudson Bay, due north of the Detroit-Windsor area. The zone of greatest thermal contrast and the associated west wind maximum in the summer are somewhat south of Hudson Bay. Therefore, in the summer months, the study area is most frequently within warm air masses. However, the flow of air through the middle atmosphere over the Detroit-Windsor area is, in the mean, from a northwesterly direction so that cooler air masses often spread south of the Detroit-Windsor area. This tendency is enhanced by the relatively cool lake waters which tend to maintain the lower temperatures of cooler air masses over the lakes, whereas the cool air tends to be dissipated by solar heating over areas of greater land surface. During these months surface winds are most frequently from a south or southwest direction, with a secondary maximum frequency of northerly winds. Precipitation is largely in the form of transitory showers so that the total amount of precipitation is somewhat greater in the summer than in the winter, although the number of hours of precipitation is much lower.

The transition from winter to summer circulation can be regarded as a relaxation of the general circulation, and tends to be gradual. As the main zone of contrast between warm and cold air masses moves northward, the paths of high pressure centers associated with the cold air masses tend to move across the continent more frequently at higher latitudes, and thus the frequency of east winds increases to a maximum in April and May because of the clockwise circulation around these pressure systems. The water temperatures of all the lakes are lower than the air temperatures at this season. A tendency for higher pressure to persist over the Great Lakes basin becomes evident in May, when a bulge of higher pressure appears on maps of the normal pressure distribution. This bulge

Table V-6. Percent Frequency of Wind Directions and Average Wind Speeds
Windsor Airport, September 1940 to December 1945

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Frequency of occurrence, percent												
N	9	12	10	12	10	7	10	11	9	10	7	8
NE	14	6	14	19	16	18	18	13	10	10	6	7
E	8	7	11	12	9	10	7	9	8	11	6	6
SE	4	4	6	6	7	6	4	7	8	5	6	4
S	8	10	10	11	13	11	14	13	15	10	12	10
SW	22	18	21	17	18	20	18	23	22	22	27	25
W	21	21	18	11	15	12	14	8	14	18	20	23
NW	9	19	7	9	7	5	7	6	8	11	12	12
Calm	5	3	3	3	5	11	8	10	6	3	4	5
Average wind speed, by direction, miles per hour												
N	12.0	14.6	13.6	13.7	10.5	8.0	7.4	7.9	8.9	9.9	11.7	11.4
NE	11.7	14.3	13.1	12.8	10.4	7.5	8.4	8.6	7.4	10.3	11.3	9.9
E	12.6	12.5	10.8	12.6	9.8	8.6	6.2	7.1	6.9	8.3	8.3	9.4
SE	8.9	10.7	12.9	8.6	8.8	5.9	6.2	6.2	6.9	6.2	8.5	7.8
S	8.2	9.3	10.9	9.4	9.5	5.7	6.8	7.3	7.5	9.4	11.1	8.8
SW	12.9	12.2	14.7	12.7	10.2	8.3	9.1	8.0	9.3	9.9	13.1	12.7
W	15.0	15.1	17.2	14.3	10.5	10.2	9.6	6.9	10.2	11.2	12.9	14.2
NW	14.5	16.4	14.8	16.2	10.8	10.9	9.6	9.6	10.1	11.5	12.9	13.2
Average wind speed, miles per hour												
	12.1	13.4	13.7	12.4	9.6	7.2	7.5	7.0	8.1	9.7	11.5	11.4

does not disappear until after October. Probably the greatest change in the circulation as it influences the Detroit-Windsor area is the shift of the mean position of the zone of maximum temperature contrast to the north of the area between April and May. A change in frequency of occurrence of a number of weather elements accompanies this shift.

The transition from summer to winter circulation shows a somewhat different trend. The west winds of the middle atmosphere increase gradually from August through January, but through October the belt of maximum wind remains at nearly the same latitude, north of the Detroit-Windsor area. For this reason, deep artic air masses do not reach the latitude of the study area until November, and the autumn months of September and October are rather similar to the mid-summer months. Surface heating by the sun diminishes rapidly in this season. This is reflected in a downward trend of temperatures. In November, however, the zone of greatest contrast between warm and cold air masses shifts south of the area. The November circulation is characteristic of a winter month,(41) and the area weather is characterized by low temperatures, cloudiness, and snow showers, typical of cold air flow over the warmer lakes. The summer maximum frequency of winds from the south shifts more to the southwest, and the secondary maximum of northerly winds disappears in November. The late fall (or early winter) months of November and December show the highest frequency of westerly winds and the lowest freqeuncy of easterly winds.

SEASONAL VARIATION OF WEATHER ELEMENTS

The remainder of the discussion of the area climatology in this chapter is based mainly on data from Detroit City Airport. The airport location is not necessarily more representative of the area than other locations, nor are the data more accurate. The general conclusions to be drawn from the data could equally well be based on data from other locations. Detroit City Airport should be considered only as an index location for the area.

NIGHTTIME ATMOSPHERE

Figure V-6 shows a summary of selected meteorological elements. The central graphs in this figure show the percentage frequency of nighttime surface inversions, as determined from radiosonde observations at Mt. Clemens and Toledo.(3) These inversion data are summarized by three-month periods, December through February, March through May, etc. The points on the curve represent three-month averages and are plotted at the mid-period month. The lower graph shows the percentage frequency of winds less than 8 mph for the hours midnight, 11 p.m., and 1 a.m. The upper graph shows the percentage frequency of clear skies (0 to 3/10 sky cover). The wind and sky cover data are based on observations at Detroit City Airport for the five-year period from October, 1949 through September, 1954, whereas the inversion data are based on three-and five-year periods at Mt. Clemens and Toledo, respectively, ending in 1950. Some discrepancy is to be expected because of this difference in period of record, but a general relationship is evident between the frequencies of surface inversions and of clear night skies and light winds. The greatest changes in frequency of conditions favorable for the development of nightime inversions, namely, clear skies and light winds, occur between April and May and between October and November. These periods of changing frequency coincide with times of shifting of the location of maximum meridional temperature gradient and associated maximum westerly winds to a position south or north of the Detroit-Windsor area.

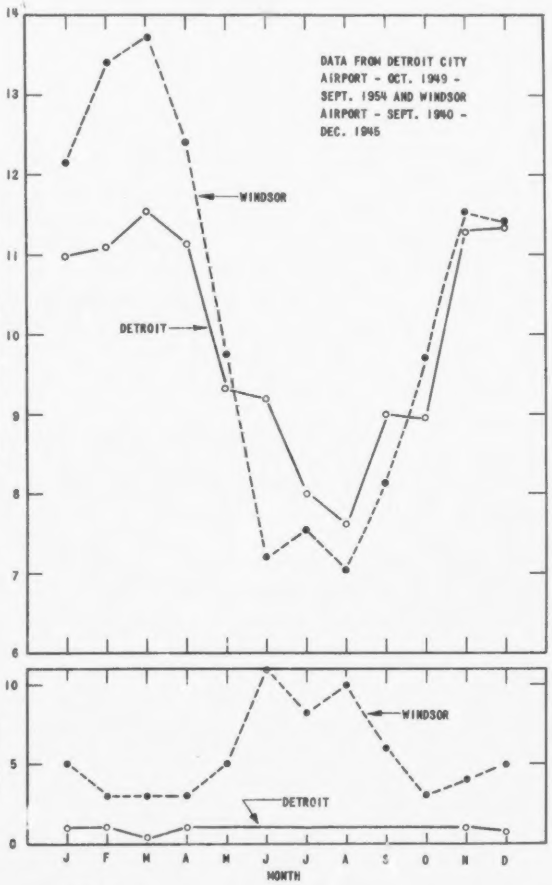


Figure V-5. Average Hourly Wind Speed and Percent Frequency of Calms

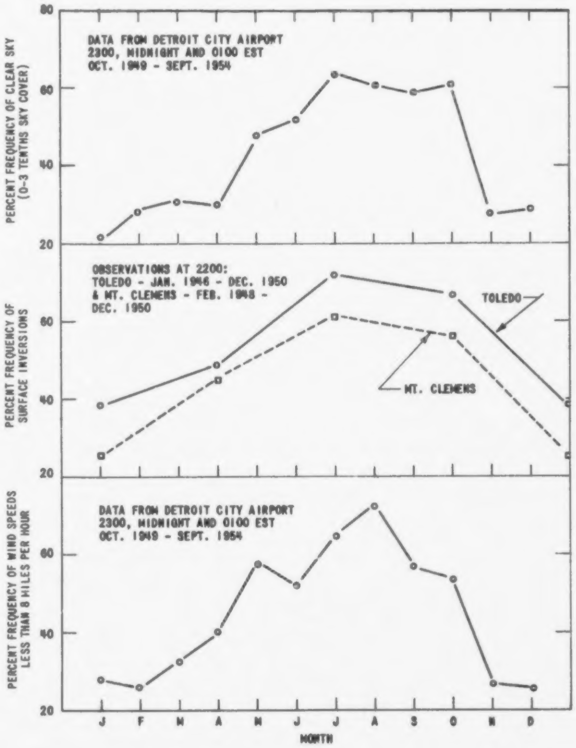


Figure V-6. Frequency of Clear Sky, Light Winds and Inversions

In terms of potential accumulation of air pollutants near the ground, both horizontal ventilation and vertical diffusion must be considered. For nighttime conditions, wind speed therefore appears to be a doubly important feature, but it should be recognized that the factors of wind speed, thermal stability, and sky condition are so interdependent that none should be considered independently from the viewpoint of air pollution climatology. The frequencies of light winds (less than 8 mph) at Toledo and Mt. Clemens during inversion conditions,(117) by coincidence, are closely approximated by the frequencies of light winds shown for Detroit City Airport. The joint frequency of inversions with light winds at 10 p.m. at Toledo and Mt. Clemens may thus be approximated by multiplying the frequency of inversions by the frequency of light winds (Figure V-6). The seasonal variation of the relative frequency of occurrence of such conditions thus can be seen to range from 10 percent or less during the winter evenings (December-February) to more than 40 percent during the summer evenings (June-August).

The intensity of nighttime inversions increases during the hours of darkness, so that the greatest intensity is reached near sunrise. The frequency of occurrence of inversions at a later hour would differ very little from that at 10 p.m., however, and the frequency of light winds would also be only slightly greater at a later hour. Therefore, the joint frequency of inversions with light winds at the time of maximum frequency of occurrence would be only slightly greater than the frequencies derived for the hour of 10 p.m.

DAYTIME ATMOSPHERE

The frequency of occurrence of light winds with a stable vertical temperature gradient is of importance for daytime as well as nighttime pollution conditions. The weather elements that favor such occurrences are somewhat different, however, and there is probably no element routinely measured which can be related particularly closely to thermal stability. The condition favoring thermal instability, namely, heating of the air by the underlying surface, is observed with heating by the sun and with cold air flowing over a warmer surface. The lowest relative frequencies of stable conditions are observed in the daytime during the summer season of maximum sunshine and during the winter with northerly winds (Tables V-7, V-8, and V-9).

Table V-7. Duration and Percent of Possible Sunshine at Detroit City Airport, 1951 to 1955.

Month	Hours and minutes	Percent of possible sunshine
January	82:07	27
February	113:06	37
March	163:22	44
April	207:05	51
May	271:44	60
June	307:41	67
July	305:43	72
August	302:44	70
September	254:21	67
October	196:20	62
November	92:10	33
December	91:28	32
Year	2384:24	53

During the colder months, the skies over the Detroit River area are predominantly cloudy; consequently, the period of sunshine is of rather short duration, averaging only about three hours a day from November through January (Table V-7). These three months are also the season of greatest temperature difference between the average air temperature and water temperatures of the Great Lakes, however, and much of the cloudiness is associated with instability from the passage of cold air across the warmer lakes.

The frequency of inversions of any type at Toledo and Mt. Clemens (Table V-8) at 10 a.m. is at a maximum during the winter season and is not much lower than the frequency of inversions of any type at 2200 (10 p.m.). The preponderance of winter inversions for both morning and evening occur with winds from a southerly direction (Table V-9) indicating that the primary cause is a transport of warmer air from the south. Almost half the inversions at 10 a.m. occur with surface winds greater than 12 mph and very few (about 5 percent) occur with winds less than 4 mph. It can be concluded that the frequency of inversions with light winds is small at 10 a.m.

The sun rises about two hours before the morning radiosonde ascent, but the frequency of surface-based inversions is only one-third as great at 10 a.m. as at 10 p.m. in spite of the

Table V-8. Seasonal and Annual Frequency of Inversions at Mt. Clemens and Toledo (Data in percent of observations at hour noted)

Season[a] - - - - - - - - -	Winter		Spring		Summer		Fall		Annual	
Time - - - - - - - - - - -	2200	1000	2200	1000	2200	1000	2200	1000	2200	1000
Mt. Clemens February 1948 to December 1950										
Inversion base at surface	25.5	8.1	45.7	7.0	61.5	2.8	56.3	7.2	47.2	6.2
Inversion base above surface but below 1000 ft.	5.8	13.2	7.1	8.4	2.9	2.4	2.5	11.2	-	-
All inversions with base below 1500 ft.	37.7	30.4	56.6	20.5	66.0	12.4	59.7	23.9	55.0	21.8
Toledo January 1946 to December 1950										
Inversion base at surface	38.6	13.8	49.1	3.7	72.6	0.5	67.3	4.6	56.9	5.6
Inversion base above surface but below 1000 ft.	3.4	19.1	8.7	10.8	2.4	5.8	1.8	18.7	-	-
All inversions with base below 1500 ft.	47.0	41.4	60.7	21.5	75.3	8.7	69.6	31.3	63.1	25.7

[a] Winter season is December, January, February; spring is March, April, May; summer is June, July, August; and fall is September, October, and November.

slight amount of solar heating before 10 a.m. The diurnal variation of wind speed (Figure V-7) indicates that maximum instability occurs during the early afternoon, at which time the frequency of inversions with light winds would be at a (negligible) minimum.

During the warm months the duration of sunshine is close to two-thirds the possible maximum, and the frequency of days with almost no sunshine (Figure V-8) becomes negligible. It can be inferred that the sun's heating acts as a destabilizing influence on all days during this season. The frequency of surface-based inversions at Toledo and Mt. Clemens at 10 a.m. EST is very small, and the occurrence of any inversions below 1500 feet can probably be ascribed to dissipating nocturnal inversions, since, as was the case for the wintertime, the diurnal variation of wind speed indicates that maximum instability occurs during the afternoon hours, after the morning radiosonde ascent.

Therefore, it appears that conditions favorable for accumulation of pollutants near the ground seldom occur in the afternoon in either winter or summer. The spring months are intermediate between winter and summer in regard to possible surface heating by the sun, but the afternoon wind speeds are at the year's maximum during March and April so that horizontal ventilation of the area in these spring afternoons is more rapid than during either winter or summer afternoons.

The autumn months of September and October are rather similar to the warmer summer months, with relatively few sunless days and afternoon wind speed only slightly greater than during the summer. The influence of solar heating diminishes rapidly, however, and it is unlikely that the afternoon instability extends through as deep a layer above the ground as during the summer, or that the duration of the daytime period of instability is as great.

When a local air current is opposed to the prevailing flow of air, a local and transitory

Table V-9. Frequency of Inversions with Various Wind Directions - Mt. Clemens and Toledo
(Data in percent of times inversion occurred with given wind directions)

Wind direction - - - - - - -		N	NE	E	SE	S	SW	W	NW	CALM
Time of day	Seasons[a]									
Mt. Clemens - February 1948 to December 1950										
2200	Winter	4	8	21	33	46	37	28	12	33
2200	Spring	34	65	50	69	74	57	20	19	67
2200	Summer	68	59	33	50	62	64	70	55	84
2200	Fall	62	56	50	71	58	61	46	39	74
2200	Annual	46	55	37	59	60	54	41	32	74
1000	Winter	11	5	0	25	30	11	2	0	20
1000	Spring	0	10	12	25	18	8	0	0	50
1000	Summer	2	7	2	2	3	2	2	0	9
1000	Fall	2	9	22	8	20	9	2	1	29
1000	Annual	3	9	6	14	16	7	2	1	20
Toledo January 1946 to December 1950										
2200	Winter	15	20	38	73	72	48	24	13	83
2200	Spring	22	38	62	80	79	60	41	25	83
2200	Summer	41	54	65	86	86	83	70	61	93
2200	Fall	53	50	74	92	86	71	38	47	86
2200	Annual	32	42	61	86	81	65	39	33	88
1000	Winter	4	0	14	31	47	23	8	0	0
1000	Spring	0	2	1	8	17	2	1	1	0
1000	Summer	0	0	0	2	1	1	1	0	0
1000	Fall	6	5	2	11	13	4	4	3	29
1000	Annual	2	2	3	11	20	8	4	1	14

[a] Winter season is December, January, February; spring is March, April, May; summer is June, July, August; and fall is September, October, and November.

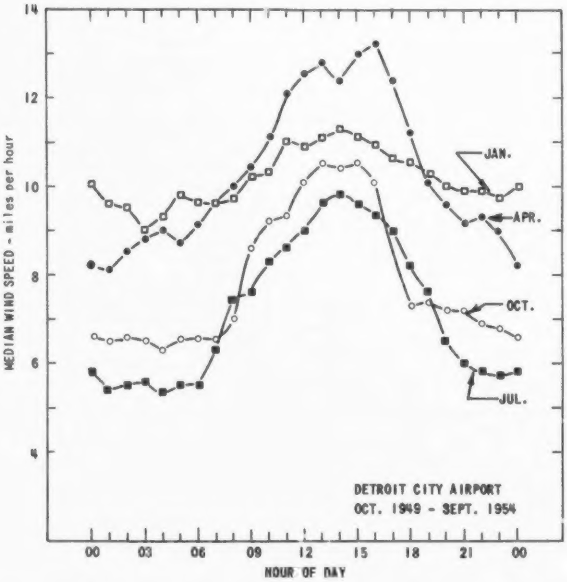


Figure V-7. Diurnal Variation of Median Hourly Wind Speed for Selected Months

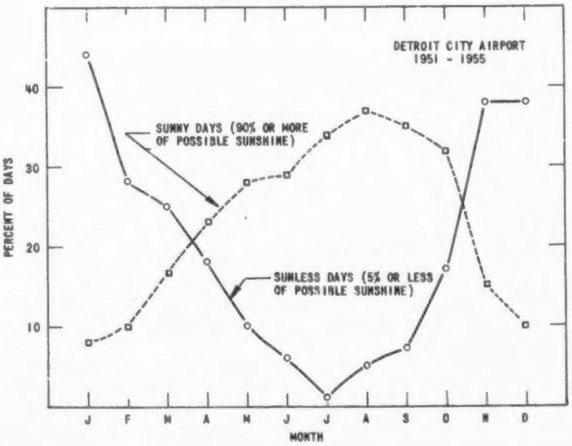


Figure V-8. Percent Frequency of Sunny and Sunless Days

zone of greatly diminished transport can develop at the convergence of the opposing air currents. Under these conditions, pollutants will accumulate. Lake breezes will tend to develop whenever water temperatures are lower than air temperatures over the land. There are occasions when local differences of air flow may occur because of cool air currents originating from Lakes St. Clair, Erie, and possibly Huron. The Detroit area is sufficiently far from Lakes Erie and Huron so that a zone of convergence between opposing winds due to these lakes would not be expected to occur over this area. A zone of convergence between a prevailing westerly flow and a local easterly current from Lake St. Clair can be expected in the area on occasion, however. A comparison of the 1:30 p.m. winds observed at Detroit City Airport and Willow Run indicates that a zone of convergence between these stations due primarily to the influence of Lake St. Clair occurs once or twice a month between May and September. Brief intervals of locally high concentrations of pollutant should occur during these months in conjunction with the development of this zone.

OTHER WEATHER INFLUENCES

In some localized air pollution conditions, the down-wash of effluent from a stack because of stronger winds can be of importance in determining concentrations of pollutant in an area downwind from the stack. An estimate of the frequency of occurrence of a given set of conditions conductive to occurrence of down-wash for any desired wind direction can be obtained from tabulations of wind speed versus wind direction contained in routine climatological tabulations.(117, 89)

Another potential cause of variation of air pollutant concentration is also related to stronger winds, namely, the blowing about of settled particulate matter from bare ground or other surfaces. Such pickup may be expected to occur with winds greater than 12 mph.(115) Therefore, the frequency of favorable wind speeds may be obtained from ordinary climatological tabulations. The frequency of appropriate ground conditions may be obtained from observations of the state of the ground made at certain observing stations.(116) The frequency of occurrence of bare ground conditions observed at Detroit City Airport at 1:30 p.m. (Figure V-9) was obtained by adding the frequencies of dry ground and bare frozen ground (states 0 and 3, Table V-10). These data indicate that favorable surface conditions occur principally from May through October. Occurrences of stronger winds are more frequent in the remaining months of the year.

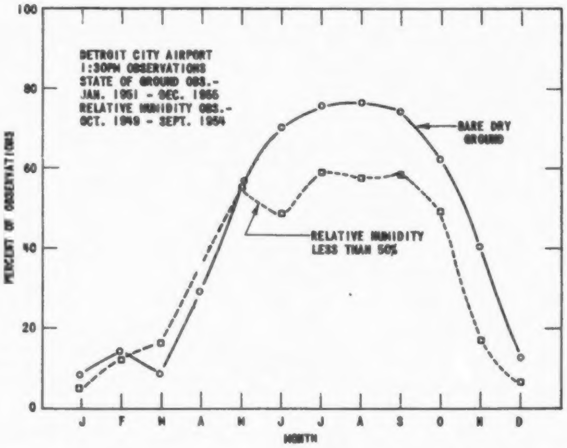


Figure V-9. Percent Frequency of Bare Dry or Frozen Ground Surface and of Relative Humidity less than 50 Percent

The joint frequency of bare, dry ground with stronger winds has been estimated by two methods (Figure V-10). If ground conditions and wind speed were unrelated, the joint relative frequency would be the product of the individual relative frequencies. In general, however, precipitation is accompanied by higher than average wind speeds, particularly during the night hours. and, therefore, there is a negative correlation between the occurrence of stronger winds and of bare and dry ground. The joint frequency obtained by multiplying the two individual frequencies (Figure V-10, upper line on graph) is, therefore, an overestimate of the true frequency desired.

The other method of estimate is to assume that a relative humidity less than 50 percent is an indicator of bare, dry ground conditions. The joint frequency of winds greater than 12 mph, with relative humidity less than 50 percent (Figure V-10, lower curve), was interpolated from a tabulation of wind speed and relative humidity.(117) The humidity limit of 50 percent provides a conservative estimate of the frequency of occurrence of bare, dry ground conditions so that the joint frequency of lower humidity with

Table V-10. Frequency of Occurrence of Various States of the Ground at Detroit City Airport, 1951 to 1955

(Data in percent of observations)

State of ground[a]	Hour of observation				Hour of observation				Hour of observation			
	1:30 am	7:30 am	1:30 pm	7:30 pm	1:30 am	7:30 am	1:30 pm	7:30 pm	1:30 am	7:30 am	1:30 pm	7:30 pm
	January				May				September			
0	3	3	2	3	57	56	56	56	74	69	75	77
1	15	10	11	14	25	25	35	34	16	19	15	12
2	4	7	8	11	18	19	9	10	10	12	9	11
3	8	8	7	4	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0
5	23	21	19	20	0	1	0	0	0	0	0	0
6	8	8	10	7	0	0	0	0	0	0	0	0
7	20	20	24	21	0	0	0	0	0	0	0	0
8	1	1	1	0	0	0	0	0	0	0	0	0
9	17	19	16	17	0	0	0	0	0	0	0	0
	February				June				October			
0	1	1	2	2	66	64	71	68	64	60	63	66
1	18	13	19	21	23	28	20	24	20	19	25	22
2	10	12	13	11	11	9	9	7	15	19	13	11
3	11	13	13	9	0	0	0	0	0	2	0	0
4	0	0	0	0	0	0	0	0	0	0	0	1
5	19	19	16	16	0	0	0	0	1	0	0	0
6	7	5	9	7	0	0	0	0	0	0	0	0
7	25	25	21	23	0	0	0	0	0	0	0	0
8	1	1	0	0	0	0	0	0	0	0	0	0
9	9	13	10	10	0	0	0	0	0	0	0	0
	March				July				November			
0	4	4	4	8	75	73	76	77	36	32	36	34
1	35	29	44	46	20	18	18	20	26	27	28	28
2	15	15	12	12	6	10	6	3	17	13	9	17
3	7	10	5	4	0	0	0	0	4	5	5	3
4	2	1	0	0	0	0	0	0	0	0	0	0
5	18	18	18	18	0	0	0	0	9	11	12	12
6	4	5	5	3	0	0	0	0	3	3	4	1
7	7	7	8	4	0	0	0	0	3	5	3	3
8	0	0	0	0	0	0	0	0	2	2	2	1
9	7	9	3	4	0	0	0	0	0	1	0	1
	April				August				December			
0	28	26	29	29	76	72	77	77	7	6	7	8
1	48	43	52	52	16	17	17	17	17	17	15	17
2	20	21	14	16	6	11	6	6	8	9	11	7
3	1	3	1	0	0	0	0	0	6	4	6	6
4	0	0	0	0	0	0	0	0	0	0	0	0
5	1	4	2	1	0	0	0	0	28	27	27	27
6	1	1	0	1	0	0	0	0	10	9	8	8
7	1	1	1	0	0	0	0	0	14	17	16	14
8	0	0	0	0	0	0	0	0	0	0	4	2
9	0	0	0	0	0	0	0	0	10	10	7	11

[a] Definition of STATES OF THE GROUND

0	Dry - no appreciable amount of dust or loose sand.
1	Moist (e.g., dew).
2	Wet (standing water in small or large pools on surface).
3	Bare and frozen (at least several inches).
4	Glaze but no snow or melting snow.
5	Ice or melting snow covering less than half of ground.
6	Ice, snow, or melting snow covering more than half of ground (but not completely).
7	Ice, snow, or melting snow covering ground completely.
8	Loose, dry snow, dust, or sand covering more than half of ground (but not completely).
9	Loose, dry snow, dust, or sand covering ground completely.

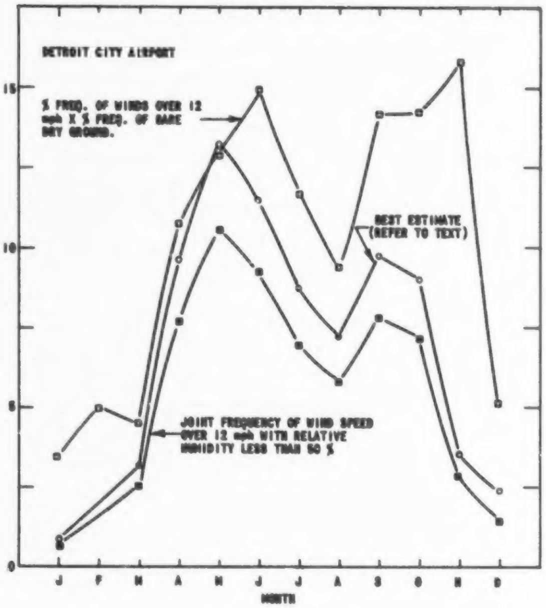


Figure V-10. Estimated Relative Frequency of Observations of Bare Dry Ground Condition with Wind Speed Greater than 12 Miles Per Hour

stronger winds is lower than the joint frequency of bare, dry ground with stronger winds. The trend of the frequencies obtained by this second method of estimate is considered more accurate than that obtained by the first method because no assumption is necessary concerning changing correlation coefficient between variables.

To obtain a best estimate of the frequency of occurrence of bare, dry ground with stronger winds, the relative frequencies obtained by the second method of estimate were increased by a factor of 1.25, obtained by calculating the following ratio: annual percent frequency of bare, dry ground conditions at 1:30 p.m. divided by annual percent frequency of relative humidity less than 50 percent at 1:30 p.m. The 1:30 p.m. observations only were used to obtain this factor because the bulk of the occurrences of lower humidity and also of stronger winds with lower humidity are during the afternoon hours; 1:30 p.m. is the most representative of these hours of the four daily observation times available.

The best estimate (Figure V-10, middle curve) indicates that the maximum frequency, about one hour in eight, of wind-blown dust occurs in May, with a secondary maximum, about one hour in ten, occurring in September. The winter months show the minimum frequency of occurrence to be about one hour in fifty for the average of the three coldest months.

A weather factor of somewhat different influence is the requirement for space heating, which is commonly measured in units of degree-days. Daily degree-days are computed by subtracting the mean temperature for a given day from a base of 65°F.; negative remainders are assigned a value of 0 degree-days, e.g., a day with a mean temperature of 26°F. is a 39 degree-day (65 - 26 = 39); a day with a mean temperature of 76°F. is a 0 degree-day (65 - 78 = - 13, assigned 0). Since degree-days are closely related to fuel consumption, the seasonal variation of degree-days should be closely related to the variation of emission of the resultant combustion products. Figure V-11 shows the normal monthly degree-day totals as well as the highest and lowest monthly totals observed

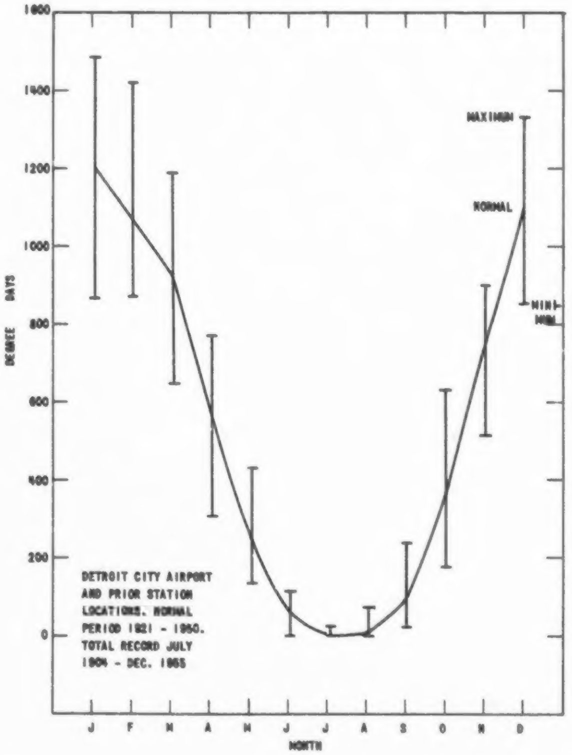


Figure V-11. Normal and Extreme Degree-Day Totals

over a 51-year period of record. These data were collected at several locations within the Detroit area because of changes of station location.

The degree-day totals at other points in the Detroit River area would tend to follow the totals above, but with slightly higher values due to the fact that most other stations are, on the average, somewhat colder. Within the urban Detroit-Windsor area, however, it is not likely that the differences of average temperature are much in excess of one degree Fahrenheit, and, therefore, the average degree-day totals would differ by only one degree-day per day, or thirty degree-days per month. It should be noted in contrast that the year-to-year variability is in excess of 600 degree-days for January, the month of greatest heating requirements.

SUMMARY

The climatology of the Detroit River area is generally favorable for dispersion and removal of air contaminants. The general features of the circulation bring a succession of changing pressure systems and air masses across the area at all times of the year. and the topography does not favor localized areas of stagnating air flow.

There are transitory periods during which conditions favorable for the accumulation of air contaminants near the ground can develop, principally during night hours in the warmer portion of the year. There is little evidence that such conditions persist for any extended period, however, and the frequency of occurrence of these conditions is not excessive in relation to that which might be expected in other geographical areas.

Chapter VI

POLLUTION FROM SOURCES OTHER THAN MARINE

INTRODUCTION

A heavy contribution of pollution to the surrounding atmosphere is to be expected from such a highly industrialized metropolitan area as the study area, including as it does the motor capital of the world with its great variety of complimentary industries for the processing and finishing of automobile parts. Residential and other space heating units are the source of considerable quantities of pollutants during the heating season. Refuse burning in incinerators, dumps, and in open fires gives rise to important quantities of pollutants. Certain commercial, transportation, and agricultural activities are also responsible for release of pollutants to the air. The purpose of this chapter is to indicate the relative magnitude of the various sources of pollution and to indicate the total quantities of various pollutants being discharged to the atmosphere.

Much of the information presented in this chapter was obtained during the course of surveys conducted by the Michigan Department of Health and members of Wayne State University. These surveys were conducted at the request of the Public Health Service and the Technical Advisory Board.

POLLUTION DUE TO USE OF FUELS

NATURAL GAS

Detailed information regarding the use of gas was available from the Michigan Consolidated Gas Company which supplies about 80 percent of the gas used in the area. About 68 percent of gas is used by residential establishments, 21 percent by industrial concerns, and 11 percent by commercial enterprises (Figure VI-1). Residential use is largely for space heating but some is used for cooking and water heating. Wintertime use is at its peak in February and is more than three times the lowest summertime use in August (Figure VI-2). Industrial use is largely for process heating, and hence there is no great monthly variation with the warm and cold seasons of the year. Commercial uses are probably about one-third for water heating and various other uses and two-thirds for space heating, as evidenced by a substantial difference in summertime and wintertime consumption rates.

The use of natural gas in the area has been increasing steadily over the last few years but not at a spectacular rate (Figure VI-1). However, the addition of a new natural gas pipeline serving the area will make larger supplies available. It is to be expected that gas will be chosen as the fuel in a larger proportion of new installations than in the past and that some existing units will be changed to gas firing from other fuels.

Gas, although usually considered the cleanest of the common fuels from an air pollution standpoint, does produce materials on combustion which are emitted to the atmosphere as pollutants. For the computation of emissions (Table VI-1), the total gas usage for 1955 was divided by 365 to obtain the average daily usage even though consumption during the winter months is two to three times as great as in the summertime. Average daily consumption is 6800 tons for the general public and 3700 tons for commercial and industrial users.

COAL

Information relative to the use of coal in the area was obtained from data concerning shipments into the area. The U. S. Army Corps of Engineers supplied information concerning shipments by boat and the Ohio Bureau of Coal Statistics concerning shipments by rail (Figure VI-3). Data concerning seasonal fluctuations in consumption rate and the proportion of total coal used by various types of establishments were not available. Use of coal for residential heating has become less popular in recent years.

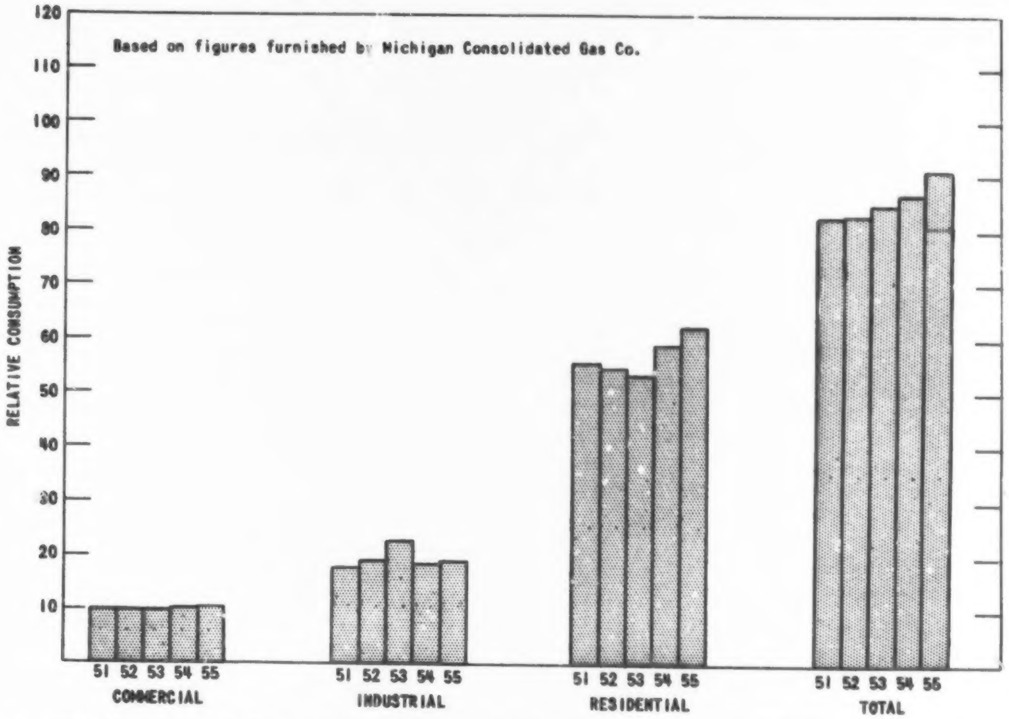


Figure VI-1. Relative Annual Consumption of Natural Gas in the Detroit-Windsor Area 1951 to 1955

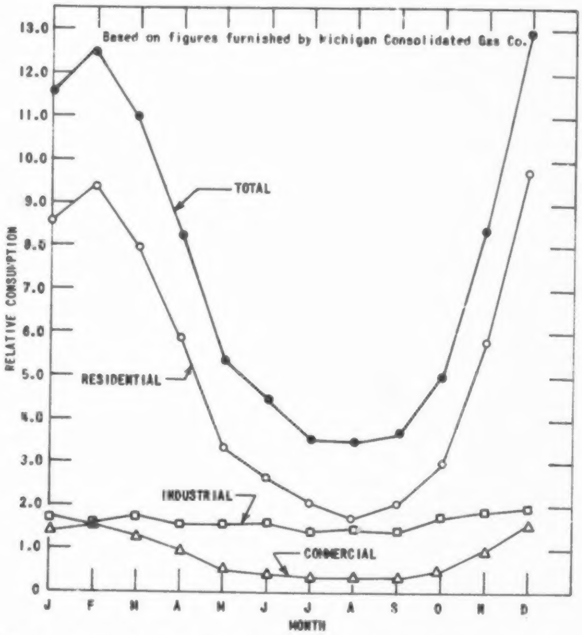


Figure VI-2. Relative Monthly Consumption of Natural Gas in the Detroit-Windsor Area - 1955

Table VI-1. Estimated Principal Emmissions from Use of Natural Gas(49)

(Data in tons per day)

Pollutant	Class of user		Total emitted
	General public	Industry and commerce	
Aldehydes	10	0	10
Nitrogen oxides	50	30	80
Acids (as acetic)	10	0	10
Organics	10	10	20
Sulfur oxides	0	0	0
Consumption	6,800	3,700	10,500

However, other applications of coal, principally metallurgical industries and electricity generating stations, have increased. The net effect has been a downward trend in total use. In 1949, total coal use was estimated at 15 to 16 million tons per year, on the basis of data gathered in a survey of coal users and distributors.

An estimate of the coal consumed by the general public (Table VI-2) for space and water heating was made on the basis of the amount of energy required to heat an estimated 300,000 residential units in the area which are heated by coal,(94) assuming a heating value of 14,000 Btu per pound and 55 percent efficiency in obtaining usable heat.

The total coal consumed by industry and commerce (Table VI-2) includes an estimated 13,000 tons per day used in the production of steel. It was assumed that 40 percent of the sulfur in this coal was, in one way or another, discharged to the atmosphere and the remaining 60 percent went into slag or coke oven by-products. Further, this amount of coal was not used in computing particulate discharges due to use of coal in industry and commerce, since total emissions from steel plants are included as an industrial emission. Also, an estimated 390 tons of coke per day are used in grey iron foundries, which amount was not used in calculating particulate discharges from use of coal, since this is included in the gross emissions from the grey iron industry. It was assumed that 60 percent of the sulfur in the coal (coke) used in foundries was discharged to the atmosphere, with the remainder resulting in coke oven by-products.

The amount of sulfur dioxide emitted to the atmosphere was estimated by assuming that there is 1.5 percent sulfur in the coal, of which 90 percent was discharged into the air and 10 percent retained in the ash. Special treatment was given to coal used by the steel and grey iron industries as described above.

The weight of particulate matter discharged to the atmosphere from the burning of coal has been estimated as less than 1 to more than 10 percent of the weight of fuel burned. Wide variation is encountered depending on the nature of the fuel, burning equipment, burning rate, air supply, and other factors. The estimates in Table VI-2 were made by assuming that 2 percent of the weight of coal used by the general public was released to the atmosphere in the form of smoke and ash. In the case of industrial and commercial use, control equipment has been installed on a great many installations which would reduce the particulate matter discharged. It was assumed, therefore, that 75 percent of the coal used in industrial and commercial units was used in units having particulate emission control equipment and the remaining 25 percent was not. For the controlled installations, it was assumed that 1 percent of the fuel burned is discharged as smoke and ash, while in the uncontrolled units, a figure of 5 percent was assumed. Special treatment was given to particulate matter discharged through use of coke in the steel and grey iron industries as described above.

Data were available to make possible the estimation of emissions of nitrogen oxides, organics, and acids from combustion of coal in heating and power boilers. However, no data were available on emission of these materials

Table VI-2. Estimated Principal Emissions from Use of Coal
(Data in tons per day)

Pollutant	Class of user		Total emission(b)
	General public	Industry and commerce(b)	
Nitrogen oxides (as NO_2)(81) . . .	40	40	80
Acids (as acetic)(81)	160	170	330
Organics(81)	100	110	210
Sulfur dioxide	280	410	690
Solids	210	190(a)	400(a)
Consumption	10,500	23,100	33,600

(a)Does not include use of coal and coke in the steel and grey iron foundry industries (See text).
(b)See text for basis of computation.

from coke ovens, necessitating an arbitrary estimate of 10 percent of the amounts discharged from burning in heating and power boilers for the coal made into coke.

It is to be noted that the data presented in Table VI-2 are in terms of average daily consumption, but nearly one-third of the total amount is consumed by the general public mostly for space heating. Thus, actual daily emission will vary considerably from the average during the summer and winter months.

PETROLEUM FUELS (Except gasoline and diesel fuel)

Data specifically indicating use of these fuels in terms of the geographic area of concern, specific uses, and seasonal variation in rate of consumption were not available, making it necessary to make very generalized assumptions.

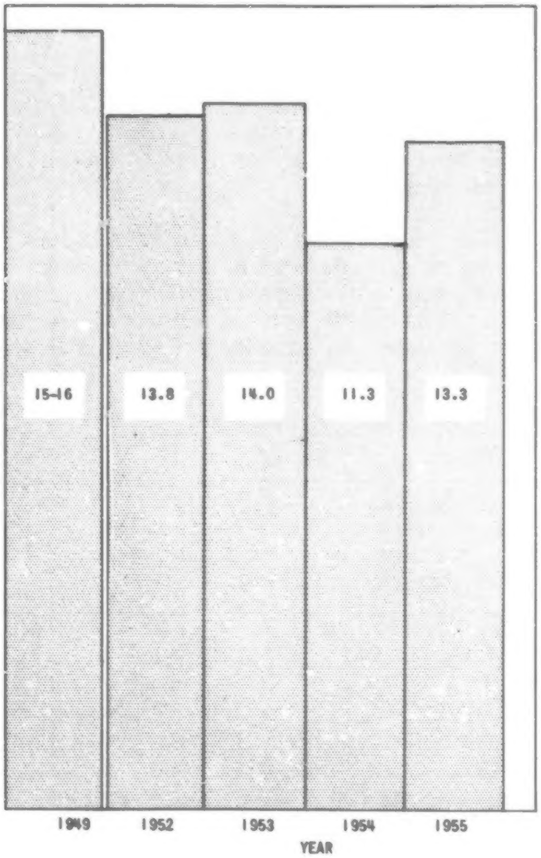


Figure VI-3. Yearly Coal Consumption in the Detroit-Windsor Area 1949-1955

Data concerning use of petroleum fuel compiled by the American Petroleum Institute(83) were used and the assumption made that 65 percent of all petroleum fuels reported as used in Michigan were used in the study area, allowing for the Canadian portion of the area. On this basis, it is estimated that about 28 million barrels of petroleum fuels are used in the study area per year. By far the two largest uses are for space heating (13.5 million barrels) and manufacturing industries (6.5 million barrels), of which the steel industry alone uses an estimated 2.5 million barrels. Of the 13.5 million barrels used for space heating, an estimated 10.3 million barrels are used in residential establishments. This residential use was estimated using information concerning the number of dwelling units heated with oil(114) and the energy used to heat an average dwelling unit for a year in the area. All petroleum fuels used for space heating will be used in much greater quantities in the wintertime than during the summer months.

Since the use of petroleum fuels has been increasing during the past few years (Figure VI-4), pollution emissions from the combustion of this fuel would also be increasing. The emissions estimated from use of petroleum fuels (except diesel oil and other automotive fuels) are given in Table VI-3.

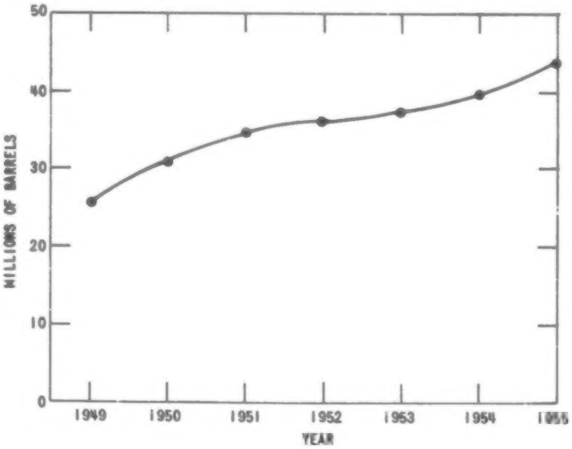


Figure VI-4. Yearly Consumption of Petroleum Fuels in Michigan (Not including gasoline and diesel fuel)

Table VI-3. Estimated Principal Emissions from Use of Petroleum Fuels[a], (49)
(Data in tons per day)

Pollutant	Class of User		Total emission
	General public	Industry and commerce	
Aldehydes (as formaldehyde) . . .	0	10	10
Nitrogen Oxides (as NO_2	50	100	150
Acids (as acetic)	60	110	170
Organics	130	230	360
Sulfur oxides	20	40	60
Solids	0	0	0
Consumption	4,200	7,500	11,700

[a] Except gasoline and diesel oil.

GASOLINE AND DIESEL FUEL

Greater recognition has been given in recent years to the contribution of automotive exhaust products to atmospheric pollution. This is due to greater use of fuels per operating unit, the higher number of vehicles per capita, and the accumulation of exhaust products in expanding urbanized areas. There is a definite upward trend in use of gasoline and diesel fuels, which is expected to continue. Estimates of the exhaust products discharged to the atmosphere from automotive gasoline and other internal combustion engines in transportation equipment are given in Tables VI-4 and VI-5. It is noteworthy that automobiles of the general public emit far more pollutants than all other transportation equipment combined. An estimated 2,900,000 gallons of gasoline are consumed daily in about 1,650,000 automobiles. About 73,000 of these autos are used in the Canadian portion of the study area. About 487,000 gallons of gasoline are used daily by 130,000 commercial vehicles. About 42,000 gallons of diesel fuel are used daily, of which about 35 percent is used by railroads, 40 percent in some 800 buses, and 25 percent in trucks.

In addition to emissions to the atmosphere due to use of gasoline in automotive engines, considerable quantities are lost to the atmosphere in marketing, filling service station and automobile tanks, and from evaporation from carburetors. All told, these losses in the study

Table VI-4. Estimated Principal Emissions from use of Gasoline in Motor Vehicles[a]
(Data in tons per day)

Pollutant	Class of User		Total emission
	General public	Industry and commerce[b]	
Aldehydes (as formaldehyde) . . .	30	0	30
Nitrogen oxides (as NO_2)	110	20	130
Acids (as acetic)	0	0	0
Organics	570	90	660
Sulfur dioxide	30	0	30
Consumption	9,000	1,500	10,500

[a] Computed using modifications of several data sources.
[b] Buses, trucks, and taxicabs.

Table VI-5. Estimated Principal Emissions From Use of Diesel Fuel(45)
(Data in tons per day)

Pollutant	Class of user			Total emission
	Buses	Railroads	Trucks	
Aldehydes (as formaldehyde)	0.2	0.1	0.1	0.4
Nitrogen oxides (as NO_2)	1.5	1.2	1.0	3.7
Acids (as acetic)	0.3	0.3	0.2	0.8
Sulfur dioxide	0.3	0.3	0.2	0.8
Solids	1.0	0.9	0.7	2.6
Consumption	60	50	40	150

area amount to an estimated 150 tons of gasoline per day.

POLLUTION DUE TO BURNING OF REFUSE

Wastes of all kinds from the operation of commercial, industrial, and residential establishments must be disposed of. The methods of disposal have a great bearing on the amount and characteristics of the air pollutants which may be released to the atmosphere.

Definitive data, which would indicate the nature of refuse created by the several classes of establishments, and data concerning the disposition of the refuse were largely unavailable. However, general opinions of various officials in the study area, experience elsewhere, and some available data were used to make general estimates of the pollution resulting from refuse disposal operations.

It was assumed that the general public produces about 2 pounds of combustible refuse per day per capita and that industrial and commercial establishments produce about one-half pound per capita per day of combustible refuse. This indicates that a total of about 4,000 tons of combustible refuse must be disposed of per day.

Data available indicate that incinerators operated for the cities of Detroit, Windsor, Ecorse, River Rouge, Grosse Pointe Park, and Grosse Pointe Shores burn about 1235 tons of refuse per day. Estimates were made that 1300 tons of refuse were disposed of in domestic incinerators and that about 400 tons per day are burned in commercial and industrial incinerators. Based on the population living in areas served by sanitary landfill disposal facilities, it is estimated that about 800 tons per day are deposited in these fills. It was reported that burning of refuse at these landfills is not common. Of the remaining 390 tons of combustible refuse produced per day, it was assumed that 100 tons are burned in one way or another and the remainder deposited in dumps where it was assumed that it would not be burned. Because of the many uncertainties involved, refuse is considered collectively and no attempt is made to attribute its origin to industry, commerce, or general public (Table VI-6).

It is known that communities having a total population of 142,000 plan to build incinerators in the very near future, and other communities having a total population of 312,000 will have to consider incineration to replace landfills or open dumps soon because of the lack of suitable land.

POLLUTION DUE TO INDUSTRIAL AND COMMERCIAL ACTIVITY

INTRODUCTION

The Detroit Metropolitan Area is the third largest manufacturing center in the United States, exceeded only by New York and Chicago. A similar industrialization exists in Windsor. The percentage of the total labor force engaged in manufacturing in the Detroit Metropolitan Area is by far the highest of any United States city. The area has the third greatest number of people engaged in manufacturing, exceeded only by New York and Chicago. The area also ranks third in the United States in value added by manufacture (Table VI-7). With this tremendous activity, it is to be expected that large volumes of air pollutants will result. There is a little

Table VI-6. Estimated Principal Emission From Burning of Refuse
(Data in tons per day)

Pollutant	Kind of burning		Total emission
	Municipal, industrial, and commercial incinerators	Other burning	
Aldehydes (as formaldehyde)	0	0	0
Nitrogen oxides (as NO_2)	0	0	0
Acids (as acetic)	0	0	0
Organics	0	200	200
Sulfur dioxide	0	0	0
Ammonia	0	0	0
Solids	10	20	30
Amount burned	1,635	1,400	3,035

[a] Calculation based on data given in Reference 12.

Table VI-7. Manufacturing Activity and Population in the Eight Largest United States Metropolitan Areas in 1950(113)

City	Population (1000)	Percent of employed persons in manufacturing	Number of employees in manufacturing (1000)	Value added by manufacturer (millions of dollars)
Boston	2,369	28.7	262	1,392
Chicago	5,495	37.5	885	5,529
Detroit	3,016	46.9	560	2,910
Los Angeles	4,367	25.0	422	2,052
New York	12,911	30.5	1,623	9,322
Philadelphia	3,671	36.6	527	2,803
Pittsburgh	2,213	37.9	307	1,708
San Francisco	2,240	20.0	173	1,049

mining and some farming in the area. Detailed data on the distribution of employment and the number of establishments in each industry group and manufacturing industry are shown in Table IV-15.

Data concerning the nature and extent of industrial and commercial activity are not usually tabulated on the basis of the area of concern in this study. Therefore, estimates were made of the extent of activity in the study area on the basis of available data for the standard geographic areas encompassing the study area. Usually the area used as a basis of estimation was the Detroit Standard Metropolitan Area, as defined by the U. S. Bureau of the Census. Data were obtained from the industry bulletins and the State bulletin for Michigan, published by the U.S. Bureau of the Census.(112) Data concerning industrial and commercial activity in the Canadian portion were obtained largely through personal contact with officials in the city government, particularly the Department of Air Pollution Control.

Pollution emissions were based on data obtained from a number of literature references, personal contact with experts in various industrial and commercial activities, and, in a large measure, on data gathered in a field survey conducted by the Michigan Department of Health under the auspices of the U. S. Public Health

Service and by staff members of Wayne State University working for the Technical Advisory Board.

An effort was made to take into account the reduction in pollution emissions brought about by control equipment, since many establishments have installed such devices.

The terminology applied to classify the various activities is based largely on the U. S. Census of Manufacturers scheme.(112) In some cases (particularly paint usage), the total area emission rate is treated as a whole and no attempt is made to attribute the emission to the myriad of activities involved in its use.

PRIMARY METAL INDUSTRIES

Blast Furnaces and Steel Mills

This group of industries includes those engaged in manufacturing pig iron and blast furnace ferroalloys from iron ore and scrap; those industries which convert pig iron, scrap and steel into steel. These industries employ about 3 percent of the manufacturing labor force and produce about 7 million tons of pig iron and steel per year. Most of the steel (about 85%) is made in open hearth furnaces. These furnaces give rise to over ~~90~~ 60 percent of the pollution caused by this class of industries. Emissions of greatest concern are particulate matter. Emission of gaseous pollutants due to use of fuels was included under the general category of pollution from use of fuels in an earlier section. The particulate matter consists principally of iron, zinc, and lead oxides, with some oxides of silicon, calcium, aluminum, and others (Table VI-8).

Iron and Steel Foundries

This group of industries includes the grey iron, malleable iron, and steel foundires en-

Table VI-8. Estimated Principal Emissions from Industrial and Commercial Activities(a)
(Data in tons per day)

Industry or activity	Pollutants		Notes
	Solids(b)	Gases	
Blast furnaces and steel mills . . .	~~640~~ 140	NA(c)	Particles are mainly iron, zinc, and lead oxides. Includes steel produced at automobile plants. Includes particulate matter (only) due to use of fuel.
Iron and steel foundries	110	60	Gases largely from core oil (mainly acrolein). Data on other gases not available. Includes particulate matter (only) from use of fuels.
Petroleum refining	0	160	Gaseous losses are largely hydrocarbons and an estimated 10 tons of sulfur dioxide.
Chemical industry	30	10	Solids include 30 tons per day from one cement plant.
Asphaltic road mixes; concrete batching and products	30	0	Largely cement and dust from sand and gravel.
Nonferrous foundries and secondary refineries	10	0	Particles are mainly zinc and copper oxides but include oxides of other nonferrous metals.
Miscellaneous industries	20	0	Includes fumes from use of welding rod (1.5 tons/day) in all activities.

(a) Does not include pollution due to use of fuels, solvents, or welding rod except as noted
(b) Includes fumes
(c) Data not available

gaged in making castings of all kinds. There are about 30 of these establishments in the area, which account for about 2 percent of the total manufacturing employment. These establishments produce an estimated 4300 tons of castings per day. Dusts arise from the cupolas and other melting furnaces, molding sand handling, shake out, casting clean-up, grinding, and chipping. Gaseous pollutants arise from core baking and cumbustion of fuels in melting metal.

Nonferrous Foundries and Secondary Refineries

Industries included in this group are those which manufacture castings and die castings of aluminum, brass, bronze, and other nonferrous alloys and those engaged in the recovery of nonferrous metals and alloys from new and used scrap and dross. There are about 100 of these establishments, but they are usually smaller shops. They are not one of the larger employers. The principal pollutants from these plants are fumes arising from metal melting operations. Some gases arise from core making, pouring operations, sand handling, and die lubrication, but these are generally of minor significance. Emission due to use of fuels in metal melting and other operations are included in the section of this chapter on use of fuels and are not included in Table VI-8 as due to nonferrous foundries and secondary refineries.

MOTOR VEHICLES AND EQUIPMENT

This is the largest industry in the study area, with large plants in both the United States and Canada. About 40 percent of all manufacturing employees work in establishments where automobiles, trucks, buses, and other vehicles, or parts for them are made. Pollution from these plants arises from production of steel, grey iron foundry operations, painting, gluing, welding, grinding, and others. However, no separate data are shown on Table VI-8 because most of these operations are included in other general catagories. Data were not obtained which would permit separate treatment of pollution data for the many plants. It is known, however, that significant quantities of pollution are emitted.

CHEMICAL INDUSTRY

This is a diverse industry group including production in the study area of materials such as sulfuric acid, sodium carbonate, lime, cement, chlorine, alkalies, ethylene glycol, detergents, phthalic anhydride, rubber chemicals, alcohols, esters, aliphatic amines, thioureas, phosphoric acid, paints, varnishes, and a host of others. Pollutants known to be emitted in quantity include sulfur dioxide, ammonia, hydrogen sulfide, sodium carbonate, lime, cement, fluorspar, phthalic and maleic acid, nitrogen oxides, phosphoric acid, sodium and ammonium sulfates, paint vehicles, and monochlorobenzene. There are, no doubt, many others. It has not been possible to obtain details on the emissions from these plants; therefore, all pollutants have been grouped as solids or gases in Table VI-8.

Collectively, the chemical industry is important in the area-employment picture, with about 3 percent of the manufacturing employment being engaged at about 200 establishments.

The large emission of particulate matter is due mainly to one cement plant. This plant is presently (1956) installing control equipment. Although the gaseous pollutants are not great in volume, they are frequently the cause of localized problems because of their odor or corrosive nature.

PETROLEUM REFINING

These establishments are of minor magnitude in the employment picture of the study area. There are less than 800 people employed in 6 refineries. However, pollution from these refineries is of importance because of the release of sizable amounts of sulfur compounds, hydrocarbons, other organic materials, and some particulate matter. The losses of all gaseous materials are given as one in Table VI-8.

ASPHALTIC AND CONCRETE USE

This group of activities consists of plants preparing hot asphaltic paving materials, ready-mix concrete, concrete blocks, and other concrete items. There are about 12 plants involved in the preparation of about 4600 tons of asphaltic road mixes per day. Some have provided fairly good control of dust emissions, while others have not. The plants without control equipment emit large amounts of dust and create very objectionable localized situations. They also emit a small quantity of asphalt fumes which sometimes cause problems. These plants are responsible for about 45 percent of the dust produced by this group of activities. There are a number of concrete batching plants where 15,000 to 20,000 tons of concrete per day are prepared. Pollution arises from transfer of cement and aggregate, and mixing the dry materials. About 28 percent of the dust produced by this group of activities arises from concrete batching plants. The other activities in this group include a number of plants which prepare concrete products from aggregates and cement, causing discharge of some dust. Some sintering is carried on which causes a rather heavy dust emission.

MISCELLANEOUS INDUSTRIAL AND COMMERICAL ACTIVITIES

All other industries not mentioned specifically heretofore are grouped in this category. It includes establishments engaged in the manufacture of food products, textiles, apparel, lumber, millwork, boxes, furniture and fixtures of wood and metal, paper, books, paper goods, rubber products, stone, clay and glass products, miscellaneous mineral products, fabricated metal goods, electrical machinery and appliances and other machinery, airplanes, boats, plastic products, and others. Typical emissions of relatively large quantities of pollutants include dust from sand drying and handling of clay; abrasive dust and lint from buffing of metals; sand and metal particles from sand and shot blast cleaning of castings; wood dust from sawing, planing and sanding; smoke fly-ash and mixed combustion gases from burning of junked auto bodies; dust from various metal grinding operations; oil mist from quenching of metal, cutting oils and drying of metal scrap from machining operations; styrene from plastics forming; chromic acid and other mists from plating of metals; cyanide and sodium carbonate from heat treating of metals; sulfuric acid and other mists from pickling of metal; and iron and other metallic oxide fumes from welding.

SOLVENT USAGE

This group of pollutants includes those arising from the use of solvents or materials containing solvents. By far the greatest source of such solvents in the air is the use of paint by industry and the general public (Table VI-9). The largest industrial users are the automobile manufacturers, accounting for about one-third of the total consumption. Paints used in industry for spray painting contain about 65 percent vehicle, while those used by the public and others in making brush application contain about 25 percent vehicle. Dry cleaning operations account for about 15 percent of the total losses to the atmosphere and are largely perchloroethylene. About 7 percent of the total solvent losses to the air arise from glue. Major users of glue are the automobile industry in the adhesive sealing operation and plastics fabricators. About 7 percent of the total arises from solvents in rubber and plastic coatings applied to fabrics and other materials and from solvents used in the molding of plastic. Degreasing operations in a variety of manufacturing operations give rise to about 4 percent of the total solvent emission. The predominant solvent used in the degreasing operation is trichloroethylene.

OTHER SOURCES OF POLLUTION

There is a certain amount of materials in the air due to natural phenonmena which are not attributable to man's activities. They include particulate matter arising from forest fires, volcanic activity, and wind-blown soil. Pollen, spores, and molds are prevalent, particularly during the late summer and fall. The life processes of vegetation and its decay, volcanoes, hot springs, and other sources release gases to the air. In some cases these natural or back-

Table VI-9. Estimated Principal Emissions Due to Use of Solvents and Solvent-Bearing Materials
(Data in tons per day)

Source or use of solvent	Loss of solvent	Notes
Paint industry usage	80	Automobile industry is largest user
Paint - general public usage	50	Includes thinners added by users.
Dry cleaning	30	Principally perchloroethylene.
Plastics molding and application of plastic and rubber coatings.	10	Mainly monochlorobenzene and isoprophyl alcohol.
Gluing	10	Automobile industry is large user.
Degreasing	10	Largely trichloroethylene.
Total	190	

ground pollution levels are a substantial portion of the total particulate-matter pollution load in an urban area.

Agricultural operations are of limited extent in the study area, but some dust is created in tillage of soil and harvesting crops. Application of insecticides and herbicides causes minor amounts of these materials to become air-borne. Some minor odor problems arise from raising of farm animals.

A number of commercial activities are carried on, some in large numbers, which create minor problems in the neighborhood but are of minor concern in the over-all pollution emission picture. These include paint spray, odor, and dust from auto body repair shops; odors from poultry and pet shops, restaurant kitchen exhausts, and barbecue stands; lint and odors from self-service and regular laundries; odors and dust from tire vulcanizing and recapping shops and dust from unpaved parking lots, drive-ins, and driveways.

Dust arises from streets and alleys. It is made air-borne by winds and air currents created by moving vehicles. The dust on the streets is deposited from the air from the many sources of particulate matter, drops off of automobiles, and is washed onto the street from surrounding areas. Large amounts of cinders and salt are placed on the streets during icy and snowy conditions which create a very dusty condition upon drying. Some of the dust is composed of particles from rubber tires and from dislodged paving material. Much effort is made by local governments to keep the streets clean. In Detroit, over 81,000 curb-miles of streets are cleaned annually; 94 curb-miles of six main arterial streets are cleaned five times a week, while 748 curb-miles of secondary streets are cleaned once a week, and 3874 curb-miles of residential streets are cleaned monthly.

SUMMARY OF POLLUTION EMISSIONS

The inventory of pollution emission presented here (Table VI-10) cannot be looked upon as complete or exact. However, the data encompass most of the major emissions and are sufficiently accurate and complete to support the following conclusions:

a. The use of coal by industry and the general public gives rise to a large amount of sulfur dioxide. The use of petroleum fuels is also an important source of sulfur dioxide.

b. ~~The pyrometallurgical industries, particularly steel-producing plants, are the source of a very substantial portion of the total particulate matter discharged. The use of coal by all types of establishments is also an important source of particulate matter.~~

c. Use of gasoline in vehicles of all sorts, along with losses of organics to the atmosphere in handling of fuels, is responsible for a major portion of the emissions of organic gases and vapors to the air. Burning of refuse in other than commercial, industrial, and municipal incinerators, petroleum refining, and burning of coal are also important sources of organic gases.

d. Pollution emissions in the Canadian portion of the study area are less than 10 percent of the total pollution emissions of the study area.

The use of coal by all
types of establishments
and the pyrometallurgical
industries are the principal
sources of particulate matter.

Table VI-10. Summary of Estimated Principal Pollution Emissions in the Study Area[a]

(Data in tons per day. Dash entires signify unknown but probably minor. NA means data not available.)

POLLUTANT	General Public								Industry and Commerce													GRAND TOTAL
	Natural Gas	Coal	Petroleum Fuels	Motor Vehicles (gasoline)	Gasoline Handling Losses	Refuse Burning	Solvent Usage	Total - General Public	Natural Gas	Coal	Petroleum Fuels	Motor Vehicles (gasoline)	Gasoline Handling Losses	Diesel - Trucks, Busses and Railroad	Refuse Burning	Solvent Usage	Blast Furnace and Steel Mills	Iron and Steel Foundries	Petroleum Refining	Other Industry and Commerce	Total Industry and Commerce	
Aldehydes	10	-	0	30	0	0	0	40	0	-	10	0	0	0	0	0	-	NA	NA	NA	10	50
Nitrogen Oxides (as NO_2)	50	40	50	110	0	0	0	250	30	40	100	20	0	0	0	0	NA	NA	NA	NA	190	440
Acids (as acetic).	10	160	60	0	0	0	0	230	0	170	110	0	0	0	0	0	-	NA	NA	NA	280	510
Organics[b]	10	100	20	570	130	160	50	1060	10	110	40	90	20	0	40	140	-	NA	150	NA	600	1660
Sulfur Oxides (as SO_2). .	0	280	130	30	0	0	0	440	0	410	230	0	0	0	0	0	(d)	(d)	10	NA	650	1090
Gases (not specified) . .	-	-	-	-	0	0	0	0	-	-	-	-	0	0	0	0	NA	60	NA	190	250	250
Total Gases	70	580	260	740	130	160	50	2020	40	730	490	110	20	0	40	100	NA	60	160	190	1980	4000
Solids	-	210	0	-	0	20	0	230	-	190[c]	0	0	0	0	10	0	[illegible] 140	110	0	90	~~[illegible]~~ 540	~~1070~~ 770

[a] Does not include carbon monoxide and carbon dioxide. Does not include marine emissions.

[b] Includes gasoline and all solvents discussed in this chapter.

[c] Does not include particulate matter discharged from use of coal in blast furnaces, steel furnaces, iron foundries or steel foundries.

[d] Included in emissions from industrial and commercial use of coal.

Chapter VII

NATURE AND COMPOSITION OF POLLUTION

INTRODUCTION

The community atmosphere is often polluted with foreign matter of natural origin and that arising from the varied activities of man. Natural contaminants include volcanic ash, soil or sand particles, sea salt nuclei, pollen, plant matter, air-borne microorganisms and various gases. Contaminants from industrial, domestic and transportation sources include a large number of both known and unidentified products. Such wastes consist of the products of combustion of solid, liquid and gaseous fuels, and effluents from physical, chemical and biological processes related to activities in the community. The distinct possibility of the further interaction of waste products by solubility, adsorption, catalytic and photochemical reactions after release to the atmosphere introduces an additional factor that serves to increase the complexity of the nature and composition of pollution.

Contaminants may be divided simply into two groups:

a. Particulate matter consisting of solid particles and liquid droplets.

b. Gases, including the permanent gases and those compounds that have boiling points below about 200°C. and are likely to be present in the atmosphere in the vapor phase.

The particulate matter may be classified according to particle size into coarse dust, larger than 5 to 10 microns diameter, and finer particles in the range below 5 microns down to about 0.1 micron or less in size. The coarse dust, which forms a considerable proportion of the material collected in dustfall receptacles, settles out of the air fairly readily. The finer material forms mechanically stable suspensions in the air, called aerosols. It is customary, however, to use the term aerosol, to cover the entire spectrum of particle size for particulate matter in the atmosphere, up to a top limit of about 100 microns.

The intensive study of the nature, composition and other chemical aspects of the urban air pollution problem has been greatly stimulated by the Donora, Pennsylvania, disaster of October 1948(61), and the perplexity of the Los Angeles smog situation(47) that has created wide-spread scientific interest since 1948-49. Prior to that time, only a limited amount of systematic research had been undertaken in this field although many investigations had been made of specific nuisance and damage problems involving smoke, dust, lead and other heavy metals, sulfur dioxide, hydrogen sulfide, fluorides, carbon monoxide and other contaminants. Among these earlier investigations, a great deal of comprehensive effort was directed toward the study of the sulfur dioxide situation in smelter areas and of the effects of this gas on vegetation by groups representing the Selby Smelter Commission(31), the National Research Council of Canada(37), the American Smelting and Refining Co.(71), the Boyce Thompson Institute(82) and others(72).

Within the decade that has elapsed since the publication of the Donora Report, a rapidly expanding volume of literature has been accumulated on the nature of atmospheric pollution in urban communities as a result of the increasing interest of scientific societies in this problem. Annual symposia on various physical and chemical aspects of atmospheric pollution have become a regular feature at proceedings of the American Chemical Society, the American Industrial Hygiene Association, the American Society of Mechanical Engineers, the Air Pollution Control Association and many other societies. A large amount of information is contained in the Proceedings of the United States Technical Conference on Air Pollution held in Washington in 1950(100), the Proceedings of the First, Second and Third National Air Pollution Symposium, sponsored by the Stanford Research Institute, and in the Air Pollution Hand Book(50).

The above literature indicates that many substances are common components of the particulate and gaseous contaminants that occur in the atmosphere of industrial communities. However, there may be wide differences in the relative abundance of certain elements and compounds from one area to another depending upon the scale of industrial operations, type and amount of fuel used and traffic density. Other differences may be accounted for on the basis of the nature of principal industries, meteorology and topography peculiar to a given area.

With respect to the Detroit River study area, an account of the land and river use and development, scale of industrialization and fuel consumption has been given in Chapter IV. Estimates of the quantities of contaminants discharged from various major sources amount to a total of about 5,300 tons daily of smoke, soot, fly ash, metallurgical and chemical dusts and fumes, sulfur oxides, oxides of nitrogen, hydrocarbons, miscellaneous organics and solvent vapors, as shown in Chapter VI.

This chapter describes the sampling equipment and analytical techniques used in the study, and it reports the nature, composition, and concentration of pollutants that were found.

SAMPLING EQUIPMENT

DUSTFALL COLLECTOR

Receptacles of similar design have been employed in Detroit and Windsor to collect the particulate matter, rain and snow that falls to ground by gravity settling. The collecting basin is a cylindrical copper can, 19-1/2 inches in diameter and 12 inches in height, containing a funnel that is 11-3/16 inches diameter at the top and tapers to a diameter of 3-1/4 inches at the bottom end. This represents a collecting area of about 100 square inches. The dustfall can and stand are shown in Figure VII-1. The top of the can contains a deflecting or guard ring, 2-1/2 inches in height to prevent the blowing out of settled dust by wind eddies. The design of this type of dustfall receptacle was engineered by the City of Detroit Bureau of Smoke Inspection and Abatement and was based on wind tunnel studies.

The dustfall cans are exposed on the flat roofs of low buildings for periods of one month or longer before collection and analysis of deposited material. In Detroit, only the water-insoluble solids are determined. A fairly complete analysis of the dust has been carried out for sampling stations on the Canadian side, consisting of water-soluble and insoluble solids, tar and other combustible matter, and ash. Dissolved impurities have also been analyzed for hydrogen ion concentration (pH), sulfate, chloride and lime. The analytical methods for the determination of deposited solids and constituents as mentioned above are described fully elsewhere(17).

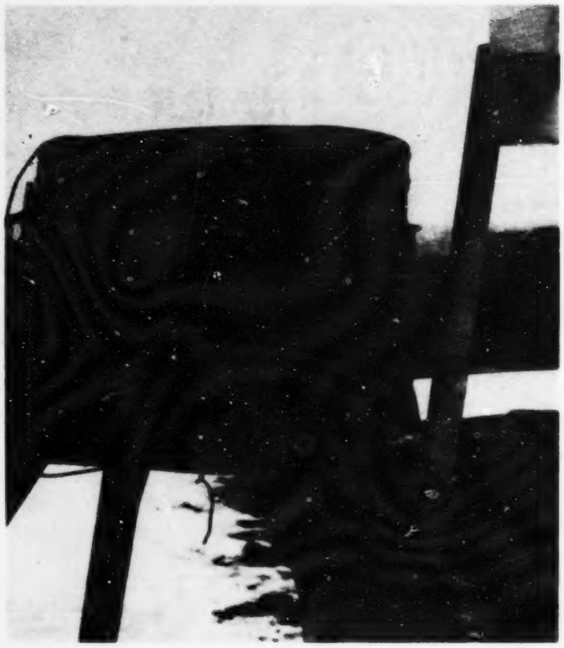


Figure VII-1. Detroit-Windsor Dustfall Receptacle and Stand

A comparative study has been made at stations in Windsor between dustfall as measured by the Detroit type of collector and that obtained by use of a simple, plyethylene plastic jar with a diameter of about 4 inches at the top and 8 inches in height. Although dustfall measurements are carried out on a routine basis in a number of cities in North America, Great Britain and other parts of Europe, there is no uniformity in design of collection equipment of internationally accepted standard. Since dustfall measurements are influenced by the shape and size of the collector, it is difficult to compare data from one city to that of another without some knowledge of the relative efficiency of collectors of various types. Some data bearing on this problem have been made available, recently, as a result of studies by Fisher at the University of Toronto on the Toronto type of collector, the British Standard, the Detroit-International Joint Commission type, and a jar used in a study at Pittsburgh as recommended by the Air Pollution Control Association(18).

HIGH VOLUME AIR SAMPLER

The high volume air sampler was used to collect suspended particulate matter by filtration. The essential parts of the sampler as shown in Figure VII-2, consisted of a blower mounted in an aluminum housing, a filter paper retaining ring located on the intake side of the blower and a U-tube manometer located on the exhaust side. The manometer was used for determining pressure differential between the inside of the housing and the atmosphere. It was calibrated with a dry gas meter to obtain the air flow in cubic feet per minute. Various models of this type of instrument were employed in successive field surveys for six-week periods or longer, on a continuous basis.

A bucket type handle was provided for carrying the sampler. When the unit was in operation it was held in place by an aluminum rod 3/4 inch in diameter and 6 inches long, located on the underside of the frame.

At most locations the sampler was mounted on a utility pole at a height of ten feet above the ground. Drop cords from the overhead power lines and crossarms were installed gratis by the utility companies in Detroit and Windsor. A metal shield was attached to protect the sample and the instrument from rain.

An accordion pleated filter paper, presenting a large surface, was used in the sampling. The rate of flow through the average clean filter was approximately sixty-five cubic feet per minute. As the sample was being collected, the air flow rate decreased as a result of the resistance of the particulates on the filter. In areas of heavy loading, at the end of a twenty-four sampling period, the flow rate often would be reduced to approximately twenty-five cubic feet of air per minute.

In operation, the filter was replaced every twenty-four hours. Manometer readings were taken before stopping the pump for removal of the filter, and immediately after a clean filter was inserted. To increase accuracy in the read-

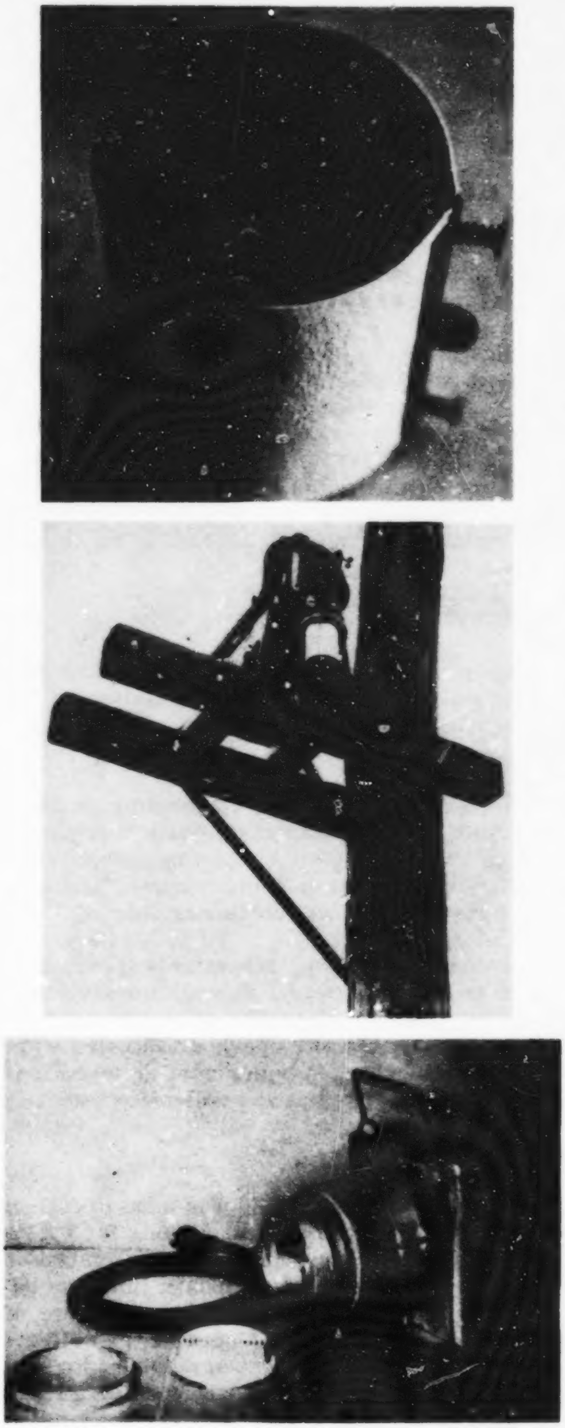


Figure VII-2. High Volume Air Sampler for Air-borne Particulate Matter

ing, the instrument was stopped and started three different times (allowing a minimum of one minute of operation to insure that the water in the manometer reached equilibrium) and a reading was taken in each instance. The average of three readings was then recorded.

In later studies the pleated filter paper was replaced by a flash-fired glass fiber filter. The fiber glass filter was supported by a specially constructed, perforated drum attached to the high volume sampler.

Calculations of the total air volume were based on the assumption that there was a constant and uniform increase in resistance, with a corresponding straight line decrease in the volume of air passing through the filter. Accordingly, the air volumes corresponding to the start and stop values were averaged and multiplied by the total number of minutes the sampler was in operation.

STANDARD IMPINGER

The standard impinger(25) was used to collect samples of atmospheric contaminants for subsequent analysis of chlorides and fluorides and for particle sizing.

The impinger apparatus consisted of a flask, the impinger tube, and plate. Air was drawn through the impinger, containing appropriate sampling fluid, with a suction pump, at a uniform rate of one cubic foot per minute.

For particle sizing, the samples were collected in dust-free ethyl alcohol for sixty minutes. Samples for fluorides were collected for a six-hour period while one-hour samples were taken for chlorides. In both sampling operations 0.1 N NaOH was used as the collecting fluid.

MIDGET IMPINGER

The midget impinger(60) was used to collect samples of atmospheric contaminants for particle counting purposes. This instrument embodies the same principles as the standard impinger but is proportionally smaller. Ten milliliters of dust-free ethyl alcohol was used as the collecting fluid. The samples were taken for ten minutes at a rate of 0.1 cubic foot of air per minute.

The sampling efficiency of this instrument is relatively the same as that of the standard impinger. Because of its light weight and compactness, the midget impinger is a commonly used instrument for procuring dust samples.

THERMAL PRECIPITATOR

The thermal precipitator(24) was also employed for procuring samples for particle sizing. In this instrument dust particles were uniformly deposited by means of thermal precipitation on cover glasses located in the head of the unit. Air was drawn past an electrically heated wire at a rate of 6.5 to 7.0 cubic centimeters per minute, by means of water displacement.

The instrument can be used to sample most aerosols, both organic and inorganic, in concentrations ranging from medium to low. Although the total air volume is small, being of a magnitude of one hundred to two hundred cubic centimeters per sample, the efficiency is reputed to be extremely high, approaching 100 percent for particles in the size range up to 5 microns and nearly 100 percent for particles in the 5- to 10-micron range.

AUTOMATIC SMOKE OR AEROSOL SAMPLERS

Several types of instruments were employed for the continuous determination of smoke, haze or aerosol concentrations. These consisted of the Owens smoke filter(62), the A.I.S.I. Automatic Smoke Sampler developed by Hemeon at the Mellon Institute(29), and the Autosampler designed by Hall for the study of aerosols in the Los Angeles District(28).

OWENS SMOKE FILTER

This instrument has been used in England for the continuous measurement of the smoke concentration of the atmosphere for many years. A measured volume of air is drawn through a small area on the periphery of a filter paper where the filtered smoke or aerosol contaminants are deposited in a spot of known area. The instrument shifts the paper to a new position at definite time intervals. The density of the spots or darkening of the paper is determined by comparison with a scale of standard color shades, calibrated to indicate the amount of aerosols in the atmosphere, Figure VII-3.

For measurements in the Windsor-Detroit area, the Owens equipment was modified by increasing the sampling time from 15 to 30 minutes or to a longer period, and the air filtration rate was stepped up to one liter per minute in the original instrument.

Within recent years, many modifications of the principle employed in the Owens instrument have been adopted in the construction of similar devices in the United States.

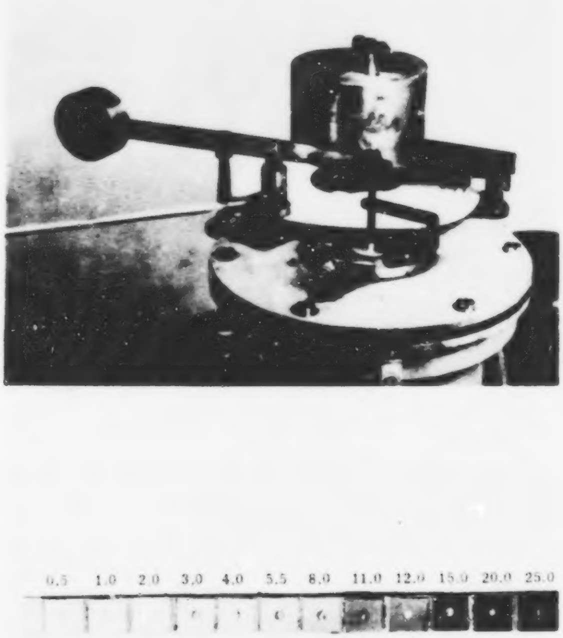
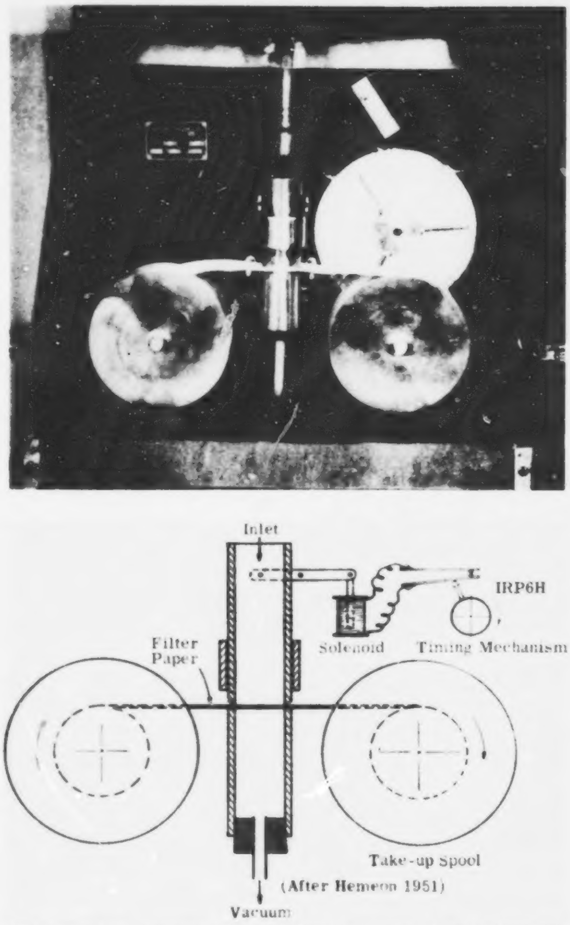


Figure VII-3. Owens Automatic Filter and Scale of Shades for use with Filter

A. I. S. I. AUTOMATIC SMOKE SAMPLER

A number of these instruments were employed on a continuous basis at various sampling sites, in the study area. Particulate matter in the atmosphere is filtered through a one-inch diameter spot on a paper tape at an air sampling rate of about 0.25 cu. ft. per minute. The sampling time may be varied from one to six hours. At the end of each sampling cycle, the tape is advanced to a fresh spot. The instrument is shown in Figure VII-4.



(After Hemeon 1951)

Diagrammatic Representation of Automatic Smoke Filter Instrument

Figure VII-4. A. I. S. I. Automatic Smoke Sampler

The density of spots on the exposed tape is evaluated by light transmission or reflectance. Results are expressed in Coh units per 1000 linear feet of air filtered. This takes into account the volume of the air sample and the area of the spot. One Coh unit is defined as that quantity of solids producing an optical density of 0.01 when deposited on the white paper.

HALL AUTOSAMPLER

In this instrument, the aerosol samples are collected by drawing the air through filter paper in a manner similar to that of the equipment developed by Owens and by Hemeon. The area of the spot is one square inch and 25 cubic feet of air volume is filtered at a uniform rate during a one-hour sampling period. The degree of darkening of the filter paper, Whatman No. 52, is measured by light reflected from the clean filter paper by means of a reflectance meter, at a wave length of 400 millimicrons.

With every set of hourly spot samples, over a 24-hour sampling period, there is drawn a parallel sample of approximately 170 cubic feet of air through a Gooch crucible containing a specially prepared asbestos filter pad. This collects sufficient particulate material for the determination of the carbon content of the deposit.

THOMAS AUTOMETER

The Thomas Autometer was used for continuous evaluation and recording of the sulfur dioxide content of the air. This instrument was developed by Dr. M. D. Thomas and his associates of the American Smelting and Refining Company(73). (Figure VII-5).

The instrument measures small concentrations of sulfur dioxide and other soluble contaminants in the air that are capable of changing the electrical conductivity of the absorbing solution. The change in conductivity is recorded as parts per million (ppm) of sulfur dioxide. A measured quantity of air flows countercurrent to a measured quantity of absorbing solution inside a uniformly heated cabinet. The absorbing solution consists of 2 to 4×10^{-3} M hydrogen peroxide in 5×10^{-5} N sulfuric acid. The sulfur dioxide in the air is absorbed and oxidized, increasing the conductivity of the solution.

The autometer was calibrated(32) after every move during the first few months of operation. However, since it was soon found that no changes occurred, it was then calibrated approximately once a month. The zero was reset, if indicated, each time solution was added or at each inspection. The continuous recording cell of the instrument was zeroed by adjusting the air inlet valve so that the air passed through the sulfur dioxide absorber tube. When more accurate calibration was indicated, a solution of known concentration was made up with sulfuric acid and used to check the reading of each of the cells. While any concentration within the limits of the instrument may be permissible, a concentration of three parts per million was commonly used.

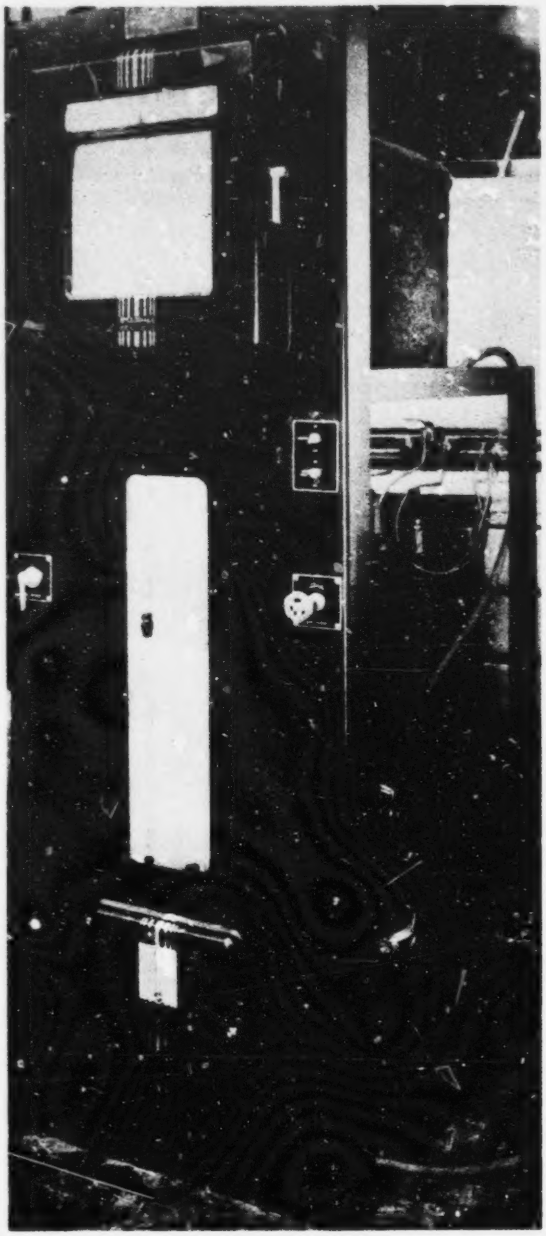


Figure VII-5. Thomas Sulfur Dioxide Autometer

To readily cover the large study area on the Detroit side, the Autometer was installed in a mobile laboratory. A complete discussion of the mobile laboratory and the operational problems of the Thomas Autometer may be obtained in a paper by Giever(22). Two Thomas Autometers were employed in the air pollution studies in Detroit.

On the Canadian side, upwards of five Thomas instruments have been employed at various fixed sampling sites, three within the City of Windsor, and two at small country towns in control areas. These were housed in small, insulated and heated buildings.

WILSON AUTOMATIC IMPINGER

This type of sampling instrument was also employed for the determination of sulfur dioxide in the atmosphere by both conductimetric and colorimetric methods. A definite volume, 50 ml. of reagent solution, is delivered into a glass impinger tube that is subsequently aspirated over a time cycle of one hour with a measured volume of air. During this cycle the aspirated solution is drained into a receiving tube, for subsequent analysis, by rotation of a turntable that holds 24 tubes. There is no provision in this instrument for the automatic recording of concentrations on a strip chart recorder, consequently its operation is automatic only insofar as the collection of gas samples is concerned. The samples must be analyzed subsequently by chemical methods. A detailed description of this instrument (Figure VII-6) has been presented by W. L. Wilson(80).

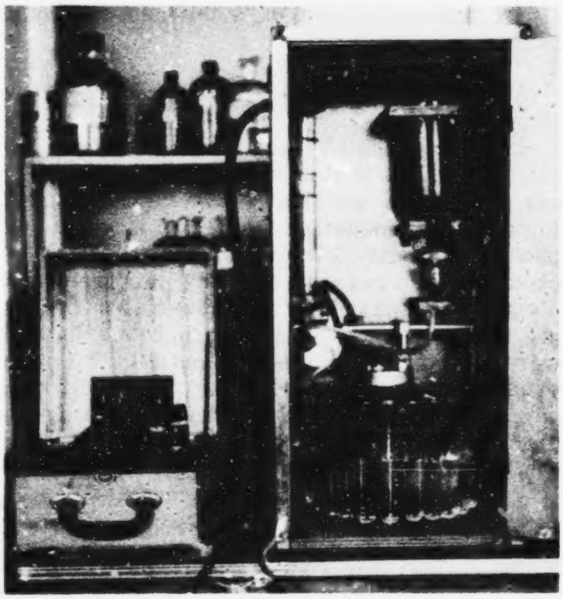


Figure VII-6. Wilson Automatic Impinger

A modified and improved model of the Automatic Impinger has been employed in the Windsor study area in conjunction with the Thomas Autometer to determine comparative differences in sulfur dioxide levels in concurrent estimations by the conductimetric method and(64) a colorimetric method based on the chromogenic reaction of sulfur dioxide or sulfite with a fuchsin-formaldehyde solution(75).

In contrast to the Thomas Autometer, the Automatic Impinger yields only mean concentration values whereas the former instrument indicates "instantaneous" or short period maximum concentrations also.

ANALYTICAL AND LABORATORY TECHNIQUES

SUSPENDED PARTICULATE MATTER

As stated previously, the high volume air sampler with accordion pleated filters was used for the collection of suspended particulate matter. The Detroit samples were numbered and inserted in correspondingly numbered metal containers and were shipped to the Cincinnati Laboratory of the Public Health Service, Division of Occupational Health, for subsequent weighing and analysis. The Windsor samples were weighed at the Windsor Laboratory of the International Joint Commission and selected lots only were shipped to the Cincinnati Laboratory for spectrographic analysis. The filter used was the type-S unimpregnated filter secured from the Mine Safety Appliance Company. The filters were about 3-3/4 inches, (9.5 cm.) in diameter and 1 inch (2.5 cm.) high and were pleated in concentric rings. Silverman and Viles (64) reported collection efficiencies of 68 percent for tobacco smoke and 99 percent for certain dusts and fumes when collected on these filters at a flow rate of 60 cubic feet (1.7 cu.m.) per minute.

The methods of weighing and spectrographic analysis are described by R. G. Keenan and D. H. Byers,(39).

Weighing Procedure

After drying in the oven, filters exposed to the atmosphere gained moisture much too rapidly for weighing. Covered ointment cans 3-3/4 inches (9.5 cm.) in diameter and 1-1/4 inch (3 cm.) high were procured in which to place the filters for weighing. In the covered cans the filters could be weighed to the nearest milligram without difficulty. These cans also served as shipping containers for the filters before and after sampling.

In the actual conduct of the study, filters prior to field use were placed in uncovered cans which were then stacked in a drying oven and dried for two hours at 110°C. Upon removal from the oven the cans were covered immediately, placed in a desicator to cool for thirty minutes, and then weighed. Upon return of the filter, the filter plus sample was dried and weighed in the same manner. The difference was taken as the weight of the sample. The samples weighed from 0.2 to more than 1.5 gm., with an average of 0.7 gm. The maximum error in this weighing procedure was about 10 percent and less than 5 percent for most of the samples. Of course, any material volatilized at 110°C. was driven off and not included. This was not considered to be serious for the analysis of metallic constituents.

Sample Recovery

According to Silverman and Viles, the type-S filter can be ashed without serious contamination of the sample. While this was true for industrial exposures such as they were considering, it did not hold for the atmospheric pollution samples. Several metals were present in the filter in larger quantities than were later found in the pollution samples. Therefore, ashing of the filters was not feasible. Washing the filters with water or acids also removed excessive quantities of metals from the filter. Washing the filters with alcohol was tried, and only calcium gave a detectable blank by this procedure.

A standard washing procedure was established. The filter was placed in 250 ml. of redistilled 95-percent ethyl alcohol in a one-liter beaker. It was thoroughly agitated by rotary and vertical motion, after which it was immersed, removed, and squeezed out about thirty times. Then the filter was transferred to another beaker with 250 ml. of fresh alcohol, and the procedure was repeated. A rubber glove was worn while performing this operation; the gloved hand was rinsed with alcohol from the wash bottle between successive filters. The filters were air-dired and saved for subsequent weighing. The alcohol washings were combined, evaporated, and wet-ashed for analysis, as will be described later.

Twenty unused filters selected from several batches were dried sixteen hours and weighed; then they were washed by the foregoing procedure. The washed filters were air-dried for two to five days before again being dried sixteen hours at 110°C. and reweighed. The filters lost an average of 41 mg. in weight. When the alcohol washings were evaporated to dryness in a weighed pyrex dish, the residues averaged 39 mg. per filter.

It was found that this air-drying and prolonged heating were necessary to remove the alcohol from the filters. Apparently some chemical or surface activity tended to retain alcohol in the filters. Fortunately, the weight of alcohol retained did not vary greatly between filters. It was thus possible to establish a correction factor for the calculation of the weight of sample removed by the washing procedure. Twenty-one samples were selected at random and washed by the standardized procedure. The alcohol washings were evaporated in weighed, 125-ml., pyrex Phillips beakers. The residue was dried at 110°C. and weighed. This residue weight was checked against the weight of sample removed from the filter as calculated from the corrected final weight of the filter. The average difference was 23 mg. The portions of the samples removed from these filters varied from 60 percent to 90 percent with an average of 72 percent.

Semiquantitative Spectrographic Method

It was anticipated that a considerable number of the metallic constituents would be present in the particulate material samples in extremely low or trace concentrations. Since it would have been extremely difficult to effect clean-cut chemical separations of most of these trace elements, it was decided to develop and to apply a rapid spectrographic procedure for this work. Furthermore, time did not permit the development of an individual spectrographic quantitative method for each of the twenty-one elements subsequently estimated in each sample. Therefore, a semiquantitative procedure which was based upon the visual comparison of the sample spectrograms and the spectrograms prepared from a series of standard solutions, was developed. This comparison of specific line spectra was made in a Jerrell-Ash, Model 200, comparator-densitometer; this instrument facilitated the comparing of spectrograms on standard plates with those on the sample plates by projecting them into juxtaposition and magnifying the projected spectraline images.

In order to prepare a series of standard solutions whose spectrograms would contain the individual line spectra of all of the desired elements over the proper concentration ranges, the first few samples were subjected to a qualitative spectrographic analysis. These analyses gave an idea not only of which elements were apt to be present in subsequent samples but also of their relative quantities. By means of this information the possible concentration ranges for each of the twenty-four different elements was calculated. The upper limit of each range was doubled in the case of certain elements, such as aluminum, iron, and silicon, to ensure sufficiently wide ranges for all samples. The initial standard solution was prepared from A. C. S. grade salts of the twenty-four elements, and eight dilutions of this initial solution were prepared after subjecting the latter to the same wet-ashing procedure to be applied to the samples.

Preparation of Sample Spectrograms

As described previously, the samples were removed from the filters by agitation in redistilled alcohol. The alcohol suspensions were evaporated just to dryness, wet-ashed with a mixture of concentrated nitric and sulfuric acids, then treated with equal volumes of concentrated hydrochloric acid and water. A portion of the sample ash was insoluble. However, all samples were made up to a volume of 10 ml in a volumetric flask, mixed thoroughly, and the insoluble material suspended by shaking immediately prior to the removal of the portion taken for spectrographic exposure. An indication that a fairly representative portion of the insoluble material was transferred to the electrode was obtained by the agreement of results of silicon determinations by both spectrographic and chemical methods on duplicate portions of the same samples.

A micropipette assembly was used to load all electrodes. Spectroscopically pure electrodes were used for the exposures in all regions of the spectrum except that in which beryllium and cadmium were read. The loaded electrodes were dried at 105°C. for one hour, then exposed in the 220-volt direct current arc source of a large Littrow spectrograph with quartz optics. Exposures in three spectral regions were required to cover the 2,200 to 4,600 A. region. The exposure periods and the slit widths were fixed for the specific regions. Eastman III-0 plates were used for the 2,250-2,850 and 2,500-3,200 regions; III-F plates were used for the 3,200-4,600 region. Plates were developed and fixed at 68°F. Twenty-three sample spectrograms were recorded on each plate. After waiting for thirty minutes, the plates were air-dried and read in the comparator-densitometer.

Chlorides, Fluorides and Sulfur

After drying and weighing to determine total particulate matter, the samples were removed from the filters by agitation in ethyl alcohol in the same manner as the samples for spectrographic examination. This alcohol suspension for each sample was transferred to an 800-ml. beaker, made alkaline by the addition of approximately 0.5 gm. of magnesium oxide, and evaporated to dryness in a steam bath.

The residue was mixed with 0.5 gm. of Eschka's mixture (2 parts MgO and 1 part Na_2CO_3) in the beaker. This mixture was then transferred to a 25-ml. porcelain crucible and covered with 0.5 gm. of Eschka's mixture. The crucible was then placed in a cold muffle furnace and the temperature gradually raised to approximately 800°C. It was held at this temperature for one hour. After cooling, the sintered sample was transferred to a 100-ml. beaker with 50 ml. of hot water and digested on a steam bath for 1/2 to 3/4 hour. The supernatant liquid was decanted through a paper filter and the residue was washed by decantation.

The filtrate was made to a volume of 100 ml. and divided into four equal aliquots. Three of the aliquots were used for the determinations of chlorides, fluorides and sulfur. The fourth was held in reserve in case any of the determinations needed to be repeated.

The sulfur in an aliquot of the sample was determined by standard chemical technique after oxidation with bromine to sulfate(106). Chloride in another aliquot of the filtrate, mentioned above, was measured by the method described by Caldwell and Mayer(9).

For the determination of fluoride, the residue from the fusion of the original sample with Eschka's mixture was dissolved in a minimum of perchloric acid. One-fourth of this solution was combined with the quarter aliquot of the original filtrate. The combined solutions were transferred to a fluoride still and analyzed according to the procedure described by N. A. Talvitie(59).

Microscopic Techniques

Standard techniques were employed for counting and for the determination of the size distribution of air-borne particulates after collection by midget and standard impingers and by the thermal precipitator. The limit of resolution for particle counting was approximately 0.5 micron, utilizing microscopic equipment with a magnification of approximately 500 diameters. With impinger samples evaluated in the Detroit Industrial Hygiene Laboratory, Dunn counting cells and a microprojector were employed according to the method of C.E. Brown of the U.S. Bureau of Mines(7).

Particle sizeing was accomplished under oil immersion at a magnification of 970 diameters, with use of a Bausch and Lomb filar micrometer for measuring the particles. In the case of dust samples collected by means of the thermal precipitator, the sample glass slides were heated over an alcohol lamp for a period of ten to twenty minutes to remove carbon particles of organic origin, as suggested in the operating instructions for this instrument. The procedure for determination of particle size has been described by Bloomfield and Dalla Valle(6).

The electron microscope was employed to study dust particles of submicron size in a number of samples collected on millipore filters during periods of haze or smog in the Windsor area. The dust particles were transferred to electron microscope screens, coated with formvar, by dissolving the membrane filter material in acetone vapor. This was done without disturbance of the dust deposit which is left on the formvar coating of the screen. The apparatus and method for accomplishing this deposition of dust particles in a manner suitable for study under the electron microscope has been described by Shore and Katz(63).

X-ray Diffraction

The application of X-ray diffraction technique to air pollution problems has been mainly in the field of quantitative determination of crystalline, free silica in mine dusts. However, in the present investigation this technique has proved a useful tool in the identification of other airborne contaminants.

The basis of this method of analysis is that each crystalline chemical compound, when powdered and placed in a monochromatic beam of X-rays, gives rise to a diffraction pattern which may be registered photographically or with a Geiger counter spectrometer, and which is unique for that compound. In a mixture, each component gives its own characteristic pattern independent of the others, so that the complete pattern of the mixture is the sum of the superposed patterns of the individual components. X-ray diffraction thus provides a powerful method of qualitative analysis, in that it shows not only the elements present but their true state of chemical combination.

The particles of the material to be identified were powdered and attached with a little Duco cement to the tip of a very fine glass fiber in such a way that the specimen projected beyond the fiber, and could be positioned in the beam with the aid of the telescope attachment on the camera. In this way the background fogging caused by scattering from the glass was greatly reduced. The diffraction spectra were recorded on photographic film held in a cylindrical cassette of 3-cms. radius in the Unicam Rotation camera, and copper radiation (= 1.54 A) was used for most of the investigation. By measuring the spectra obtained on the film, the spacings of the planes giving rise to these may be calculated. The material may then be identified by referring to the A. S. T. M. index which lists all the compounds on which powder data are available in terms of their three strongest lines(63).

Chromatographic Absorption

This technique was applied to the separation and identification of individual plynuclear aromatic hydrocarbons in a mixture of air contaminants. Some samples were collected on fiber glass filters, employing a high volume sampler. Larger samples were obtained from material collected over a period of 2 months on fiber glass filters at the air intake of an air-conditioning unit located in a Windsor high pollution area.

The separation of single aromatic hydrocarbons from other interfering compounds was effected by extracting the sample with organic solvents and fractionating the extract by chromatographic adsorption analysis, using columns of alumina of varying degrees of activity. The identification of the hydrocarbons in the fractions of eluate was carried out by measuring the ultraviolet absorption.

GASES

Sulfur Dioxide

Although most of the measurements on sulfur dioxide in the Windsor-Detroit area were carried out by means of continuous analyzers of the Thomas type based on the conductimetric method, a limited study was made of a colorimetric method involving absorption of the gas sample by aspiration through 0.1 Normal sodium hydroxide solution containing glycerine with subsequent addition of a reagent containing fuchsin and formaldehyde. Prior to use, about 0.2 microgram per ml. of sulfur dioxide in the form of sodium metabisulfite was added to the reagent(53). The method, with a few modifications, was similar to that described by Paulus, Floyd and Byers(55). Although rated as a specific method for sulfur dioxide, it was found to be affected by the presence of nitrogen dioxide. This interference became increasingly significant when sulfur dioxide levels in the atmosphere were low or of about the same order of magnitude as the nitrogen dioxide contamination.

Nitrogen Dioxide

Analyses for nitrogen dioxide in the Windsor atmosphere were made with an absorbing reagent consisting of a mixture of sulfanilic acid, N-(1-naphthyl)- ethylene diamine dihydrochloride and acetic acid according to a procedure described by Saltzman(59). The air was sampled for nitrogen dioxide at an aspiration rate of 2 liters per minute, concurrently with the sampling for sulfur dioxide by the operation of modified Wilson Automatic Impingers(53).

Aldehydes

The Goldman - Yagoda method(34) was employed to determine the content of aldehydes in the Windsor atmosphere. Air was drawn through a scrubber equipped with a fritted glass bubbler containing a solution of one percent sodium bisulfite at a rate of 1 to 3 liters per minute. The sample was then titrated with dilute iodine solution in the presence of starch indicator, to remove excess sulfite. A definite quantity of a sodium acetate buffer solution was then added and the liberated sulfite was titrated with 0.01 N iodine solution to a faint blue endpoint. The method is not subject to interference by acid gases such as sulfur dioxide, halogen gases, or volatile organic acids. All aldehydes and acetone vapor are included in the estimation.

Oxidant

Oxidant or ozone levels in the Detroit atmosphere were determined at the Detroit Industrial Hygiene Laboratory, Herman Kiefer Hospital, at intervals over a period of several years from 1952 to 1954, by means of an alkaline potassium iodine method. The air sample was drawn through a fritted glass absorber, at a sampling rate of 3 to 5 liters per minute, and the oxidant absorbed in a solution of specially pure grade one-percent potassium iodide in 0.1 N sodium hydroxide.

In the analytical procedure, a small amount of hydrogen peroxide is added to the alkaline sampling solution after aspiration, to oxidize any sulfur dioxide to sulfate. After heating the sample solution to the boiling point to decompose excess peroxide, the solution is cooled, acidified with acetic acid to a pH of 3.8, and the optical density of the solution is recorded with a spectrophotometer at a wave length of 352 millimicrons. The concentration is determined by reference to a standard curve prepared by making appropriate additions of standard potassium iodate solution to the sampling solution. A blank determination is carried out on the same sampling solution. The method has been described in detail by Ralph G. Smith of the Detroit Bureau of Industrial Hygiene(67).

NATURAL AIR-BORNE RADIOACTIVITY

The natural radioactivity of air-borne particulates has been determined twice daily for several years during the period March 1952 to December 1954 at a location on the first floor of the Herman Kiefer Hospital by the Detroit Bureau of Industrial Hygiene. All samples were collected on millipore type AA filters by filtration of suspended particles over 30 - minute periods from 15 cubic ft. of air. The morning samples were obtained over the period 0800-0830 and the afternoon samples at 1500-1530.

Radiation measurements were made with a Landsverk quartz fiber electrometer, commencing at about one minute after air sampling was completed and continuing for 30 minutes. The activity of the sample was recorded in terms of the scale divisions of fiber drift per hour, after correction for background drift.

The activity measured is due almost entirely to alpha particles emitted from a mixture of short lived isotopes, half-life about 40 minutes, indicative principally of radon and daughter products, presumably of natural origin.

Coincident with the above radioactivity determinations, measurements were made of the reflectance of the millipore filter deposits to indicate the degree of darkening or soiling of the filters from air-borne impurities.

RESULTS OF PARTICULATE SAMPLING

Particulate contaminants constitute a large fraction of the overall pollution in the Windsor-Detroit study area. For the determination of pollution levels and subsequent study of the nature and composition of this material, two main methods of collection were employed. In the case of relatively coarse particulates, the samples were collected in dustfall receptacles of the type already described. Air-borne particulates were collected by filtration, either by high volume samplers for weight concentration measurements and chemical analysis, or by means of automatic smoke samplers for measurement of the soiling index of the air. For particle counting and size distribution analysis, the samples were collected mainly by use of impingers or the thermal precipitator.

DUSTFALL OR COARSE PARTICULATES

The distribution of deposited matter or dustfall was determined from the results of sample collections from twenty sampling sites on each side of the Detroit River. The locations of these stations are indicated on Figure VII-7 and VII-8.

Deposited matter contains a large amount of relatively coarse particles which range in size from over 100 microns down to about 5 microns or less. Most of the mass of material collected in dustfall receptacles is over 44 microns in size (325 sieve mesh, Tyler). Dustfall rates afford an indication of the extent of contamination over an urban area by such relatively coarse particles as fly ash and soot from the combustion of fuels; the dust discharged to the air from miscellaneous grindings, metallurgical, chemical and other industrial operations; and the particulate matter re-entrained by the wind.

The variation in monthly mean dustfall values, expressed in tons per square mile per month, in the City of Detroit is illustrated in Figure VII-9. The data represent the 4-year period, 1950-1953 inclusive. Detroit dustfall figures are indicative of insoluble solids only and not of total solids, as the results do not include the water-soluble fraction. The mean of all monthly values for each year shows a steadily rising trend from 59.8 tons per sq. mile in 1950 to 72.1 in 1953. However, this trend is not maintained in later years. Over the period 1954-1956, mean dustfall values have varied from 63.5 to 73.1 tons per square mile, as shown in Table VII-1. Pos-

Table VII-1. Detroit Dustfall[a]
Annual Means and Values for Heating and Nonheating Seasons

Tons per square mile per month

	1950	1951	1952	1953	1954	1955	1956
Annual mean	59.8	62.1	64.1	72.1	63.5	73.1	67.0
Nonheating season, 7 months April to October inclusive	66.9	53.4	59.6	63.6	51.2	64.9	61.3
Heating season, January, February, March, November, and December .	49.9	74.2	70.3	83.9	80.7	84.5	75.1

[a] The data represent water-insoluble solids and not total solids.

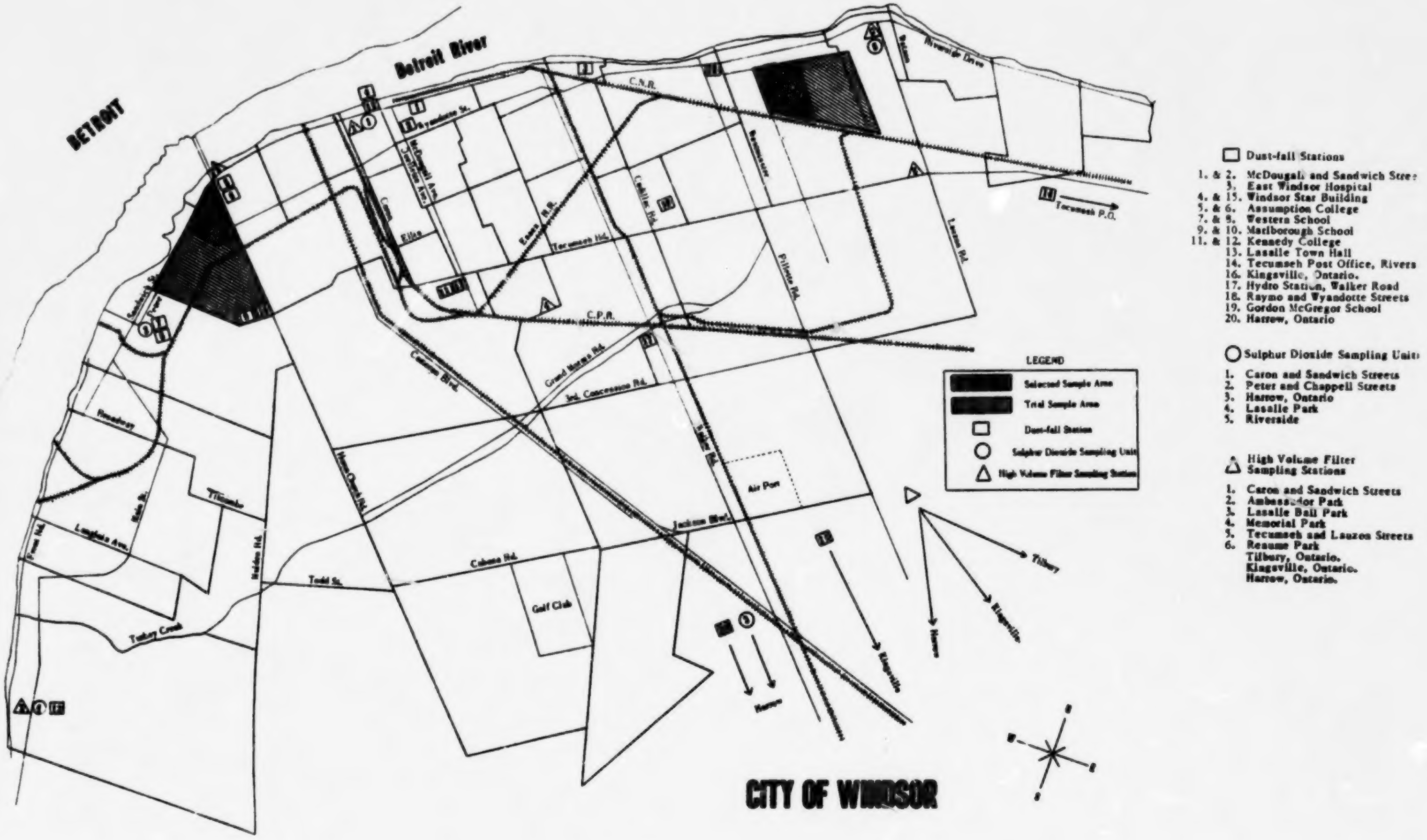

DETROIT
Detroit River
Wyandotte St.
McDougall Ave.
Jefferson Ave.
Ellis
C.N.R.
C.P.R.
Essex R.R.
Tecumseh Rd.
Cadillac Rd.
Walker Rd.
Pillette Rd.
Lauzon Rd.
Riverside Drive
Tecumseh P.O.
Grand Marais Rd.
3rd Concession Rd.
Jackson Blvd.
Cabana Rd.
Todd St.
Golf Club
Air Port
Tilbury
Kingsville
Harrow
CITY OF WINDSOR
LEGEND
Selected Sample Area
Trial Sample Area
Dust-fall Station
Sulphur Dioxide Sampling Unit
High Volume Filter Sampling Station
Dust-fall Stations
1. & 2. McDougall and Sandwich Stre
3. East Windsor Hospital
4. & 15. Windsor Star Building
5. & 6. Assumption College
7. & 8. Western School
9. & 10. Marlborough School
11. & 12. Kennedy College
13. Lasalle Town Hall
14. Tecumseh Post Office, Rivers
16. Kingsville, Ontario.
17. Hydro Station, Walker Road
18. Raymo and Wyandotte Streets
19. Gordon McGregor School
20. Harrow, Ontario
Sulphur Dioxide Sampling Unit
1. Caron and Sandwich Streets
2. Peter and Chappell Streets
3. Harrow, Ontario
4. Lasalle Park
5. Riverside
High Volume Filter Sampling Stations
1. Caron and Sandwich Streets
2. Ambassador Park
3. Lasalle Ball Park
4. Memorial Park
5. Tecumseh and Lauzon Streets
6. Reaume Park
Tilbury, Ontario.
Kingsville, Ontario.
Harrow, Ontario.

Figure VII-7. Location of Canadian Sampling Stations

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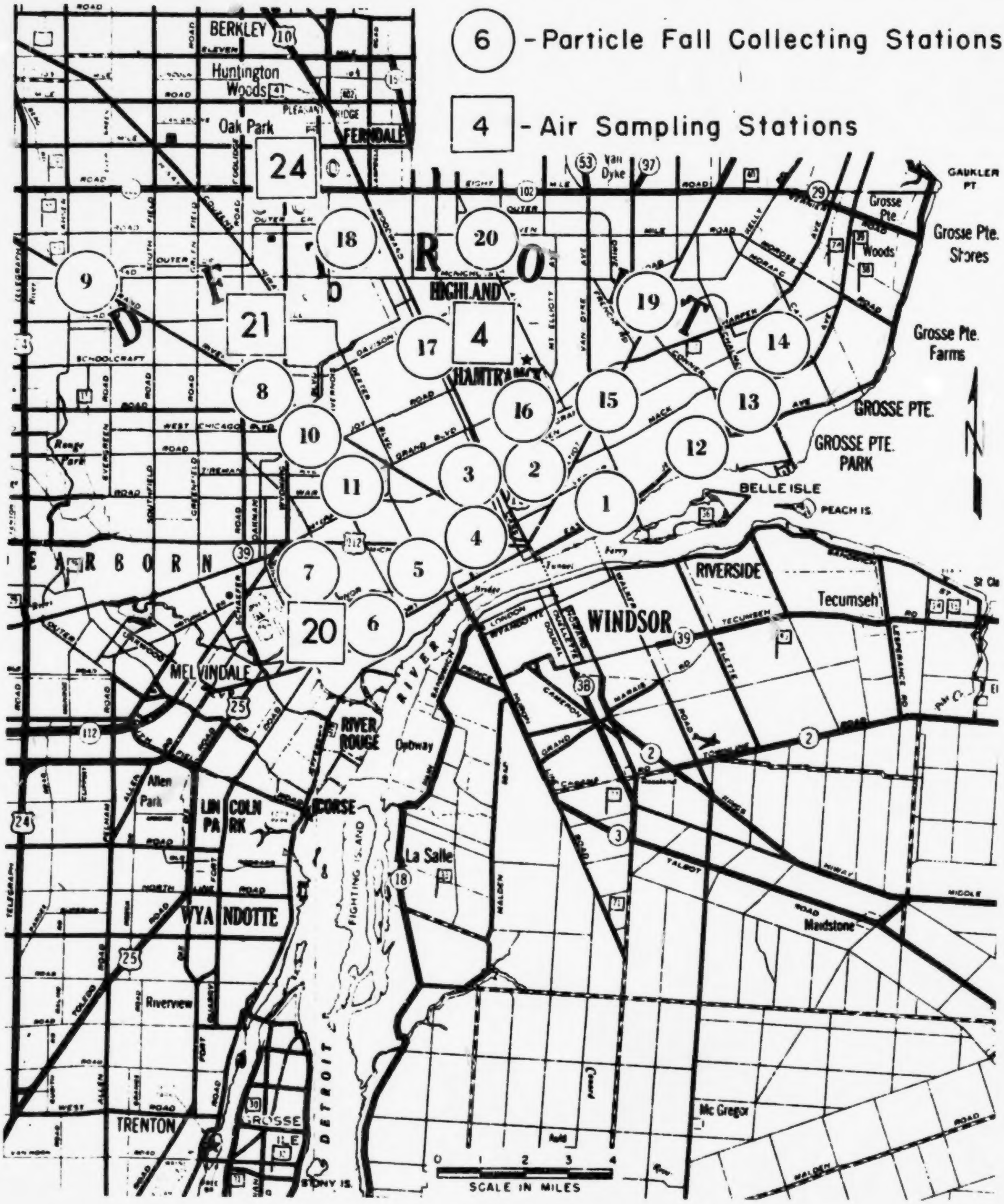

6 -Particle Fall Collecting Stations
4 -Air Sampling Stations
BERKLEY
Huntington Woods
Oak Park
FERNDALE
24
20
18
9
21
HIGHLAND
4
17
19
14
8
HAMTRAMCK
16
15
13
10
12
3
2
11
1
4
5
7
20
6
GROSSE PTE.
GROSSE PTE. PARK
Grosse Pte. Shores
Grosse Pte. Woods
Grosse Pte. Farms
GAUKLER PT
BELLE ISLE
PEACH IS.
DEARBORN
RIVERSIDE
Tecumseh
WINDSOR
MELVINDALE
RIVER ROUGE
Ojibway
ECORSE
LINCOLN PARK
Allen Park
La Salle
FIGHTING ISLAND
WYANDOTTE
Maidstone
Riverview
TRENTON
GROSSE ILE
STONY IS.
DETROIT RIVER
Mc Gregor
0 1 2 3 4
SCALE IN MILES

Figure VII-8. Location of United States Sampling Stations

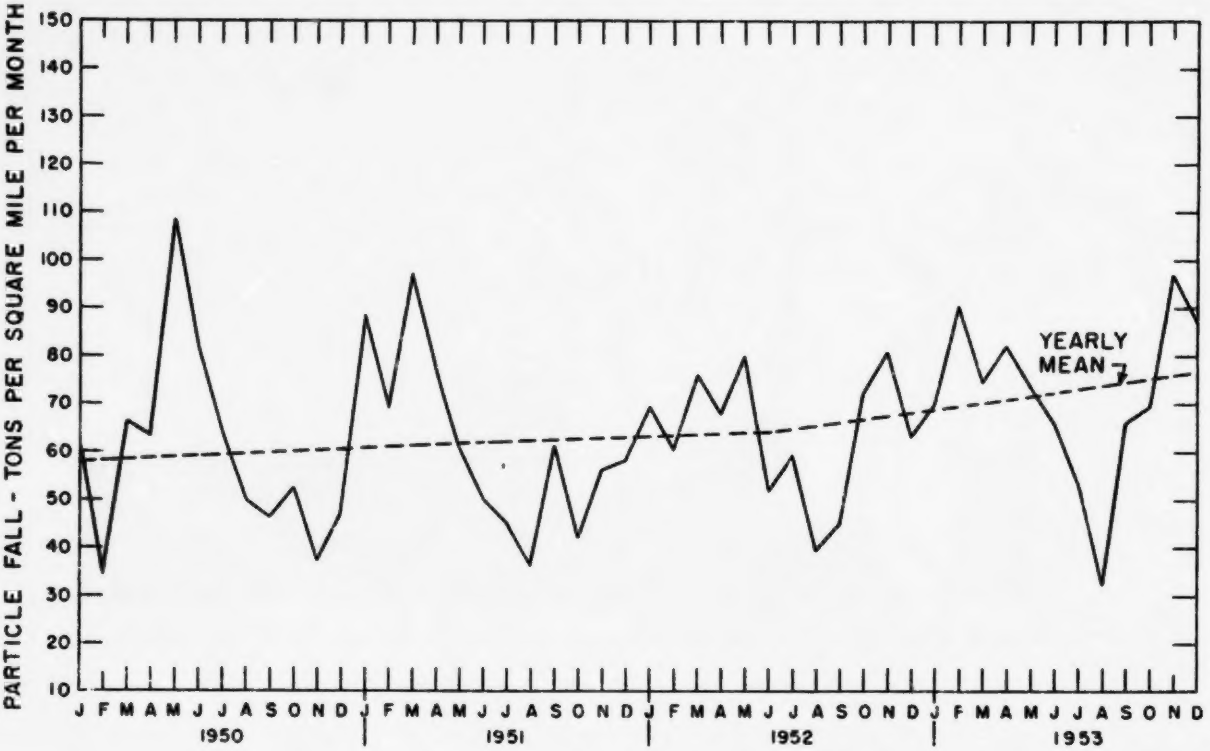


Figure VII-9. Detroit Dustfall

sibly, the increased consumption of natural gas for domestic heating purposes has had a bearing on the above trend.

A separation of the dustfall data into values representing the heating and nonheating seasons indicates that there was a distinct rise in dustfall during the heating season of five months in six of the seven-year period 1950-1956.

The distribution of Detroit dustfall in three areas within city limits is illustrated in Table VII-2. Within the area bounded by the Detroit River and 5 Mile Circle, there is little change in rates of particle fall but a relatively sharp drop occurs beyond these limits, in the zone that is predominantly residential.

Table VII-2. Mean Dustfall[a] In Areas Within Detroit City Limits

Tons per square mile per month

	Area 1	Area 2	Area 3	Mean
1954	70.2	70.6	49.6	63.5
1955	83.8	81.1	54.3	73.1
1956	73.4	78.4	49.2	67.0

Area 1 - within Grand Boulevard
Area 2 - between Boulevard and 5-mile circle
Area 3 - between 5-mile circle and city limits
a - The data represents water-insoluble solids

Within the City of Windsor the dustfall in a central area, designated as a high pollution area. bounded by the Detroit River on the north side and extending about one mile inland, almost parallel to the river, is roughly comparable to that within areas 1 and 2 of Detroit. Beyond this zone, for several miles to the east, south, and southwest, in an area that is predominantly commercial-residential, the pollution level is relatively moderate. In the suburban-rural section which include Riverside, Tecumseh and McGregor, the pollution area has been designated as low. The mean dustfall values and distribution of chemical components over the period 1951-1955 are shown by the data in Table VII-3. Differences in rates of particle fall or deposition within the high and low pollution areas are demonstrated more clearly by the chart, Figure VII-10. A similar comparison is shown in

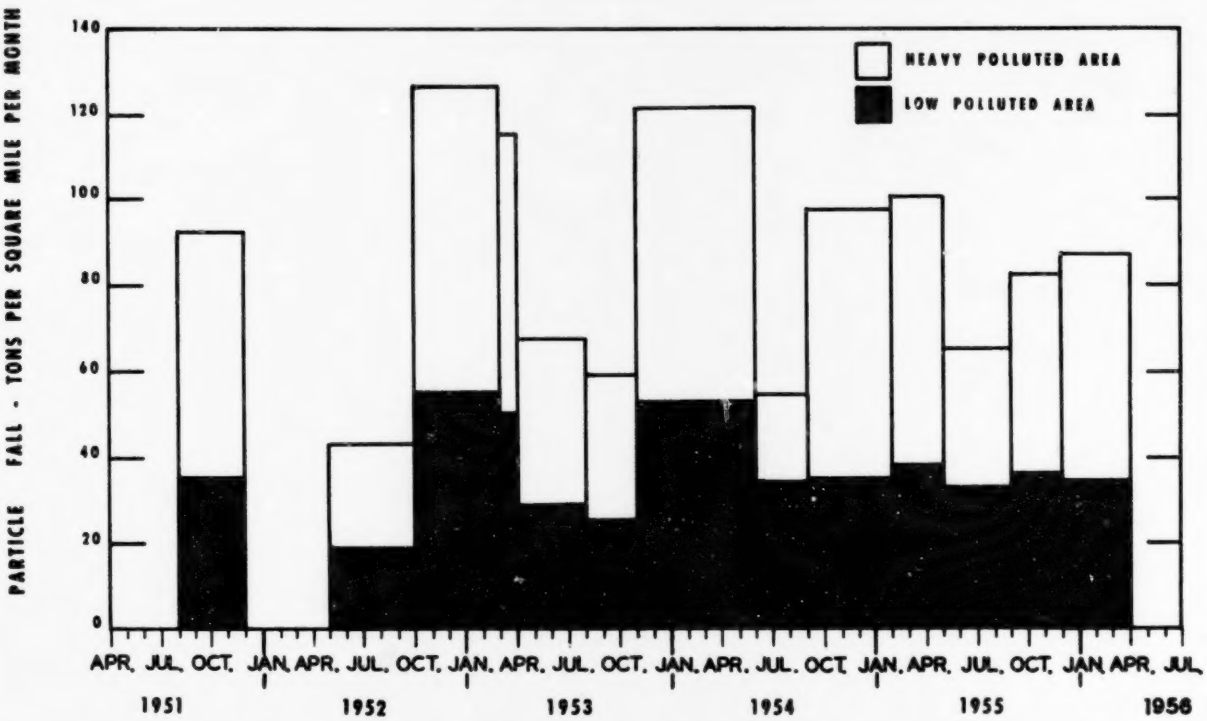


Figure VII-10. Windsor Dustfall

Table VII-3. Dustfall in the Greater Windsor Area

Yearly Mean Values for Deposited Contaminants Tons per square mile per month

Test Period	Total Solids	Insoluble (Water)	Soluble (Water)	Tar (CS_2)	Other Combustible Matter	Ash	pH
Area of Relatively Heavy Pollution							
(Aug.-Nov.) 1951.	92.2	69.2	21.1	1.48	21.0	45.9	5.4
(May-Dec .) 1952.	74.3	58.9	15.4	1.39	15.0	42.1	6.5
1953	88.4	66.3	21.6	0.68	20.7	41.7	5.8
1954	96.9	64.2	32.8	0.27	22.9	36.8	5.2
1955	83.1	58.3	24.5	-	22.0	37.4	5.7
Area of Relatively Moderate Pollution							
(Aug.-Nov.) 1951.	50.9	40.9	11.3	0.59	12.1	26.2	6.4
(May-Dec.) 1952.	49.0	39.6	9.3	1.37	9.5	29.0	7.3
1953	59.1	46.8	12.1	0.69	11.5	31.3	6.2
1954	65.3	44.7	20.6	0.37	11.8	33.2	5.5
1955	47.4	33.2	13.7	-	9.0	25.0	6.0
Area of Relatively Low Pollution							
(Aug.-Nov.) 1951.	35.9	26.9	8.8	0.61	11.0	16.1	6.8
(May-Dec.) 1952.	31.1	26.6	6.1	0.97	5.4	19.0	7.1
1953	38.3	28.2	10.3	0.48	7.0	19.6	6.4
1954	42.4	28.4	14.2	0.11	7.6	20.8	5.8
1955	35.6	26.4	9.3	-	8.2	18.3	6.2

Figure VII-11 for the monthly mean dustfall values in the Canadian areas containing the households chosen for the Health Study. The mean values for the distribution of chemical components of the deposited matter in the three pollution areas investigated during the period of the Health Study are given in Table VII-4.

For the greater Windsor area, the mean rate of particle deposition in the heavy pollution area, over a five-year period since August 1951, has been about 1.56 times greater than that in the area of moderate pollution and 2.34 times the mean rate for the so-called low pollution area. Some industrial sections of Windsor are exposed to a dustfall rate about five times greater than that of the small towns of Harrow, Kingsville and Simcoe, Ontario.

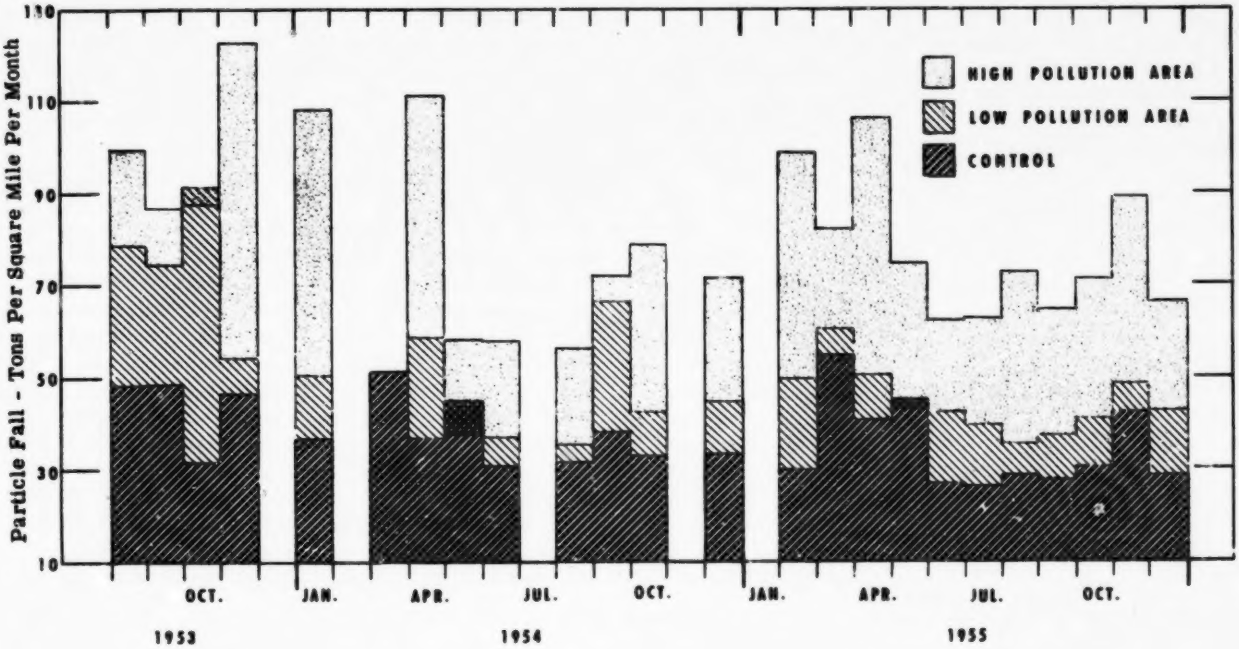


Figure VII-11. Monthly Dustfall in Canadian Health Study Area

Table VII-4. Distribution of Dustfall in Health Study Areas

Yearly Mean Value for Deposited Contaminants in Tons per Square Mile per Month

Test Period	Total Solids	Insoluble Matter (Water)	Soluble Matter (Water)	Tar (CS_2)	Other Combustible Matter	Ash	Dissolved Impurities			
							pH	Lime	Chloride	Sulfate
- Windsor High Pollution Area -										
1953 (Aug.-Dec.)	91.2	72.2	19.0	0.26	19.5	53.3	5.7	2.2	0.24	9.9
1954 " "	75.7	50.7	25.9	0.32	13.7	34.7	5.4	2.1	0.34	12.6
1955 " "	65.5	43.9	21.6	0.28	12.5	30.4	5.7	0.8	0.42	11.9
- Windsor Low Pollution Area -										
1953 (Aug.-Dec.)	59.8	45.8	14.0	0.21	12.2	33.4	6.0	1.7	0.32	7.2
1954 " "	39.4	23.0	16.2	0.31	5.7	16.8	5.6	0.6	0.08	7.6
1955 " "	34.6	21.1	13.4	0.26	6.1	13.1	6.0	0.2	0.17	6.3
- Control Area -- Harrow, Kingsville and Simcoe, Ontario -										
1953 (Aug.-Dec.)	32.4	22.4	10.0	0.17	5.5	16.8	6.6	0.9	0.15	4.3
1954 " "	27.6	16.8	10.9	0.14	4.2	12.4	6.1	0.5	0.19	4.2
1955 " "	24.1	14.9	8.6	0.25	4.0	10.7	6.2	0.1	0.10	4.1

The water-insoluble solids consist of tar, other combustible organic matter, carbon and ash. The water-soluble fraction of total solids contains inorganic material such as sulfate, chloride, soluble calcium salts, nitrate and other dissolved impurities that are acidic and tend to decrease the pH of a solution. In the Greater Windsor area the insoluble solids on the average amount to about 73 percent of the total solids representing dustfall. The remainder of about 27 percent comprises the water-soluble material, some of which is collected in rain and snow. In many cities of North America where dustfall is measured, the results represent only the insoluble solids because the water-soluble fraction is not determined.

There is a distinct seasonal variation in deposition of total solids from lower values in summer months to higher rates in winter months. On a percentage basis the insoluble solids constitute over 80 percent of the total material collected during the summer months. This figure decreases to about 67 percent in the winter period. There are corresponding changes in the percentages of water-soluble components as shown in Table VII-5. The pH of the water-soluble fraction is distinctly more acidic in the winter months than in the summer period.

An estimate has also been made of the fraction of inorganic material or total ash in Windsor dustfall. The yearly mean for all areas is 75.5 percent by weight of the total deposited matter. In the high pollution area the percentage is 72.4 and this rises slightly to about 77-78 percent in the moderate and low pollution areas. The balance of the dustfall consists of combustible and organic matter, about twenty-seven percent in the high pollution area and about twenty-two percent in the areas of lower pollution.

It is useful to compare the Windsor-Detroit dustfall values with data obtained in other cities. However, this cannot be done directly because the results are influenced greatly by the shape and dimensions of the type of collector used, even when there is no undue influence from other variables involved in the location of sampling stations with respect to nearby buildings and stacks. Some solution to this problem has been found in the data from studies carried out by Fisher at the University of Toronto(18). He has compared dustfall collections at identical sites with various types of containers, including the Detroit-Windsor type, the British standard, the type used in the city of Toronto, and a simple stainless steel can recommended by the Air Pollution Control Association. At Windsor, a comparative study has been made of the dustfall values obtained with the type of collector normally used in the Windsor-Detroit study area and a polyethylene jar conforming to A. P. C. A. standards. From all this work a series of

Table VII-5. Seasonal Variation of Dustfall Components in Greater Windsor

May 1952 to March 1956

SEASON	Total Solids (Tons per square mile per month)	Water Insoluble Solids (Percent)	Water Soluble Solids (Percent)	pH of Water Solution
- Area of Heavy Pollution -				
Summer	58.2	81.5	17.6	6.1
Winter	101.5	67.1	33.0	5.5
- Area of Moderate Pollution -				
Summer	40.3	85.3	14.5	6.5
Winter	67.3	68.8	31.1	5.9
- Area of Low Pollution -				
Summer	28.2	85.5	14.3	6.6
Winter	42.2	66.6	33.4	6.0

factors have been obtained to correct the dustfall data reported for various cities so as to make a more valid comparison with the Detroit-Windsor dustfall. This comparison is presented in Table VII-6. No allowance has been made for the fact that most cities report only insoluble solids as dustfall or sootfall. The known exceptions to this in the Table are the results reported for Windsor, Toronto and the cities in the United Kingdom, where both soluble and insoluble fractions are included.

Trends in Dustfall Rates

The dust collected in a dustfall jar or can represents the gravitational fall-out of particulate pollution. It consists of two components, namely, particulate matter that has been emitted from a source and has fallen more or less directly into the can and ground pick-up of dust and dirt by the wind and subsequent fall-out. The total monthly dustfall is influenced by a number of factors, including distance from major sources of emission. Large particles will normally be deposited within a few hundred yards of the point of emission. During the winter heating season, the discharge rate of particulate combustion products will be greater than in the summer. Other emissions vary in quantity with time. Prevailing wind direction will be important in dustfall totals because of rapid fall-out of large particles downwind from sources. Wind speed will affect the rate of gravitational fall-out and will affect entrainment or re-entrainment of surface dust. A wet ground surface or a snow cover will inhibit ground pickup. On the other hand, spring ploughing associated with dry weather and brisk winds can result in a relatively large ground pickup. Precipitation will have some influence on the fall-out process and, of course, influence the state of the ground.

A detailed examination of the Detroit-Windsor dustfall data indicates the following relationships:

Table VII-6. Dustfall for a Number of Cities (51, 98, 92)

City	Year	Dustfall Reported in tons per square mile per month	Factor	Dustfall Corrected[a] in tons per square mile per month
1. Detroit, Area 1	1956	73.4	1.00	73.4
Area 2		78.4		78.4
Area 3		49.2		49.2
2. Windsor, Industrial	1955	83.1	1.00	83.1
Residential - Commercial.		47.4		47.4
Residential - Semi-rural		35.6		35.6
3. Toronto, Industrial	1956	46.1	1.85	85.3
Industrial - Residential		23.6		43.7
Residential - Semi-rural		11.6		21.5
4. New York	1956	69.8	1.225	85.5
	1955	63.8		78.2
5. Chicago	1947	61.2	1.225	75.0
6. Pittsburgh	1951	45.7	1.225	56.0
7. Cincinnati	1946	34.0	1.225	41.6
8. Los Angeles	1948	33.3	1.225	40.8
9. Rochester	1942	26.4	1.225	32.3
- United Kingdom -				
10. Birmingham	1939-44	27.8	1.85	51.4
11. Bristol	1939-44	11.6	1.85	21.5
12. Glasgow (East)	1939-44	29.6	1.85	54.8
13. Leeds (Park Square)	1939-43	35.9	1.85	66.4
14. London (Westminster)	1939-44	29.1	1.85	53.8
15. Manchester (Philips Park)	1939-44	42.9	1.85	79.4

[a] Dustfall values for other cities have been corrected to correspond roughly to the data obtained with the type of collector used in Detroit-Windsor.

a. Graphs of dustfall data for the country towns of Kingsville and Harrow (about 10-25 miles south of Windsor), Riverside in East Windsor, and two matched collectors at Assumption College in Windsor for the period August, 1953 to September, 1956 (Figure VII-12) showed areas of high, medium and low dustfall. In nearly every month, collectors at Assumption College indicated the highest dustfall, while collectors at Kingsville or Harrow indicated the lowest dustfall rate;

b. Seasonal trends were more marked in high and medium pollution areas where industrial activity and population density are greater than in other areas;

c. Matched collectors at Assumption College gave moderately concordant results;

d. Dustfall at Assumption College and sulfur dioxide at Peter and Chappell Streets followed much the same seasonal and yearly patterns, (Figure VII-13). This conformity suggests that dustfall is as valid a pollution index as is sulfur dioxide;

e. Seasonal dustfall trends varied somewhat from year to year. The record was not long enough to reach any conclusion concerning the "normal" seasonal trends;

f. Monthly precipitation frequency was tried as a meteorological predictor of dustfall rate, based simply on the number of hours per month during which precipitation occurred at Detroit City Airport. A correlation coefficient of 0.53 was found with Assumption College dustfall totals, i.e., large dustfalls were associated with large precipitation frequencies, as shown in graph, Figure VII-14. However, it is suggested that the two variables may be associated only in point of time, that during the winter heating season there are larger emissions and also more precipitation. There need be no direct relationship between the two variables;

g. The Detroit dustfall data for 1950 to 1953 were examined. In 1950, dustfall minima

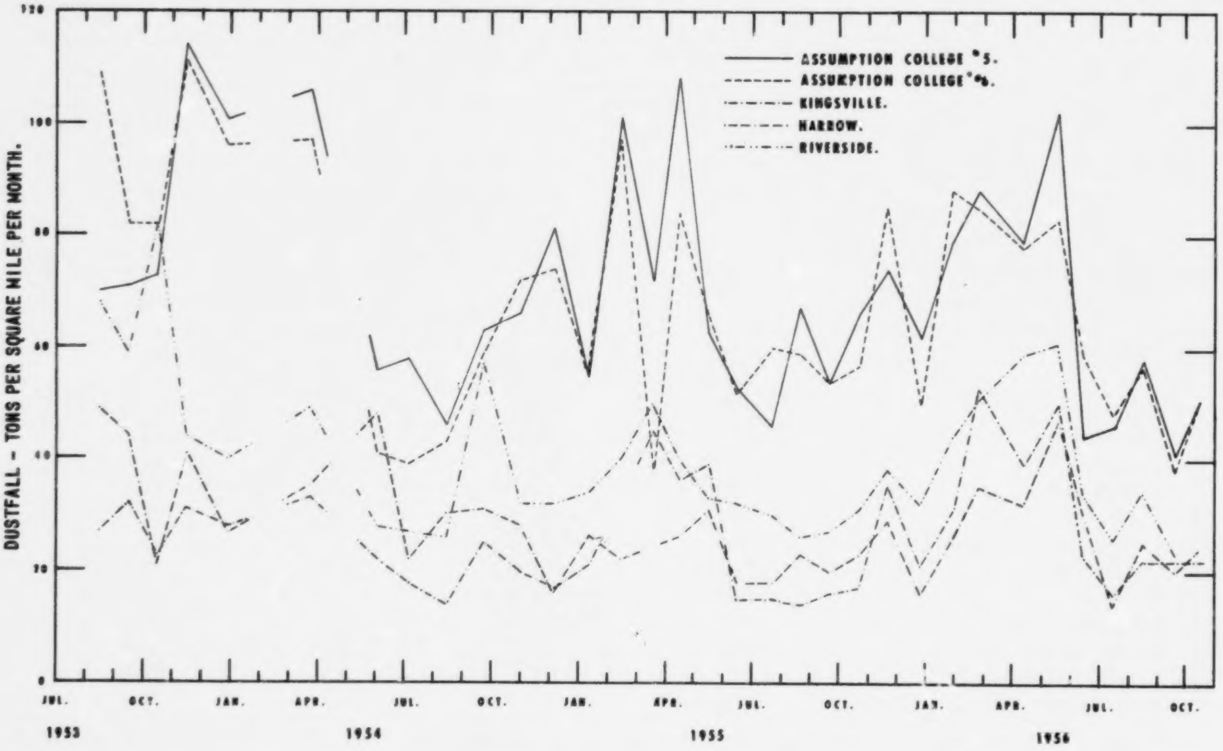


Figure VII-12. Dustfall for Assumption College, Windsor, Riverside, Kingsville, and Harrow

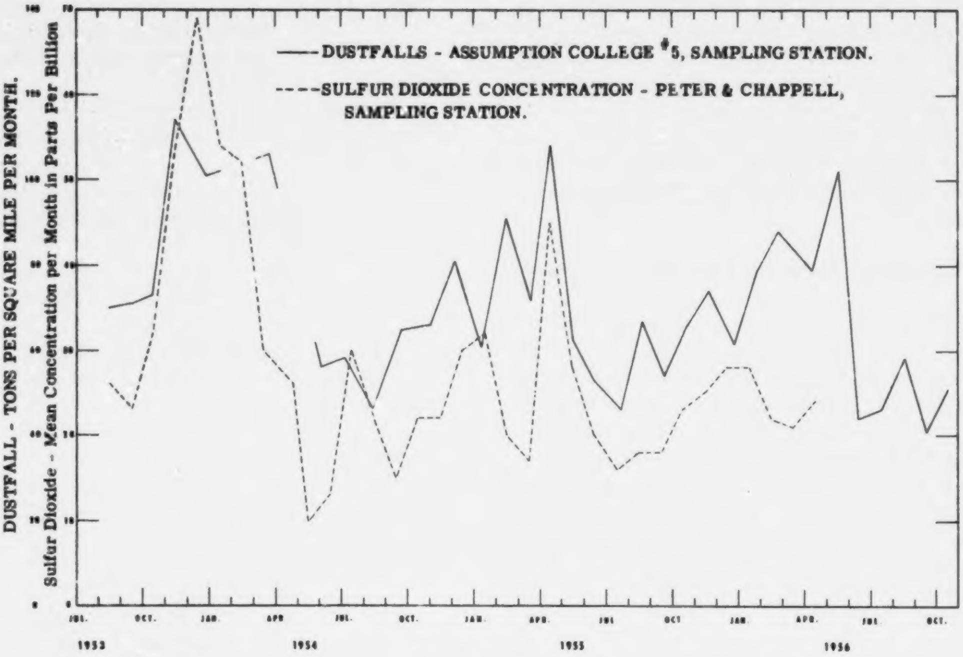


Figure VII-13. Comparison of Monthly Dustfalls and Mean Monthly Sulfur Dioxide Concentration - Windsor, Ontario

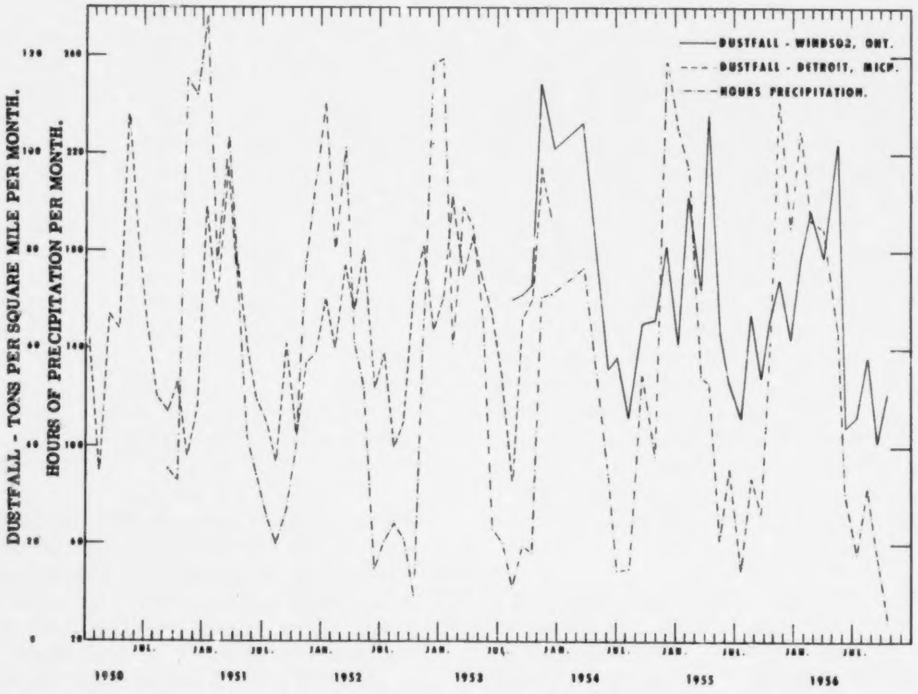


Figure VII-14. Comparison of Monthly Hours of Precipitation with Detroit and Windsor Dustfall

occurred in February and November, while, in 1953, maxima occurred in the same months. The two 1950 months were wet, while the 1953 months were dry -- anomalies to the positive correlation found in the Canadian data. It is possible that these are examples of the re-entrainment mechanism, a second-order magnitude effect which appears when the seasonal emission variation is removed.

AEROSOLS OR AIR-BORNE PARTICULATES

In 1951, studies of the variation in aerosol pollution levels were carried out with networks of high volume samplers at 31 stations during the period May 7 through June 17 in the Detroit area, and at 26 stations during the period October 24 to December 5 in the Windsor area. The weight concentration in micrograms per cubic meter of air was determined for each sample collected over a 24-hour sampling period and the filtered deposits were analyzed subsequently by spectrographic methods for 24 elements.

The comparative aerosol loadings for the City of Detroit survey are given in Table VII-7. Based on the median values, there was a threefold increase approximately between the most polluted area and the cleanest area. It is noteworthy that nine of the ten stations within one mile of the Detroit River were represented in the first fifteen stations that had the highest median concentration values. Lowest median values were found in residential areas remote from local pollution sources. The spread between minimum and maximum levels of pollution varied greatly at each station. The highest median value was 357 micrograms per cubic meter and the peak level reached over any 24-hour sampling period was about 1008 micrograms per cubic meter. On the average, the pollution level for all stations during this survey period was about 215 micrograms per cubic meter. By frequency distribution the vast majority of the samples fell within the range of 100 to 350 micrograms per cu. m. Only a few samples were in the range below 50 or greater than 750.

Table VII-7. Comparison of Total Particulate Matter at 31 Sampling Stations in the Detroit Area - May 7 to June 17, 1951

		Micrograms per cubic meter of air		
Position	Station	Median	Maximum	Minimum
1	15	357.1	873.2	121.0
2	4	344.2	736.8	114.0
3	19	342.8	712.6	109.2
4	11	281.5	640.6	99.1
5	25	275.9	1008.8	80.6
6	1	265.6	548.8	124.0
7	2	265.4	507.1	98.4
8	10	257.4	552.0	79.5
9	20	246.7	631.4	45.7
10	30	245.9	878.5	96.6
11	14	234.5	523.2	95.6
12	6	224.5	493.8	78.0
13	26	221.4	431.2	88.6
14	16	218.5	440.8	99.2
15	7	217.2	403.6	101.3
16	24	211.4	600.7	42.7
17	9	209.6	464.9	106.1
18	8	209.0	482.8	86.9
19	3	202.3	401.7	86.7
20	31	201.0	454.6	62.9
21	12	198.0	428.6	57.8
22	27	184.4	367.8	32.0
23	5	177.4	449.2	61.6
24	28	164.6	359.4	30.7
25	18	161.0	438.1	58.2
26	17	154.9	375.8	72.2
27	13	154.2	364.6	72.6
28	22	147.4	456.6	39.2
29	21	146.2	351.0	46.1
30	29	138.2	376.4	11.8
31	23	121.6	455.3	8.3
Mean		215.5		
Median		211.4		

A summary of the data for the survey on the Canadian side of the Detroit River is shown in Table VII-8. As noted on the United States side, the most heavily polluted stations were those located relatively close to the Detroit River or near industrial sources of pollution. However, the aerosol concentrations in Greater Windsor were considerably lower than in Detroit. At the Windsor sampling station that showed the highest mean particulate level, the concentration was about three times greater than that found for the semirural sites at Tecumseh, about eight miles east of Windsor, and McGregor, about fifteen miles south of Windsor. There was a great spread at any one sampling station be-

Table VII-8. Comparison of Total Particulate Matter at 26 Sampling Stations in the Greater Windsor Area - October 24 to December 5, 1951

Position	Station & Location	Micrograms per cubic meter of air		
		Mean	Maximum	Minimum
1	L 1-1/2 miles south of river	238	436	82
2	P near Detroit River	222	467	84
3	J Windsor, near Detroit River	216	402	92
4	K 1/2 mile south of river	214	448	36
5	Z Walkerville, 1-1/2 miles south of river	204	378	59
6	D Windsor, near Detroit River	200	450	93
7	H Windsor, near Detroit River	200	318	112
8	G 1-1/2 miles south of river	188	421	12
9	Q 3/4 mile south of river	180	552	65
10	F 3/4 mile south of river	180	325	32
11	I Windsor, near Detroit River	177	379	50
12	C West Windsor	174	350	27
13	E near Detroit River	169	334	37
14	M 2 miles south of river	166	521	24
15	O Walkerville, 1 mile south of river	163	380	14
16	R 1-3/4 miles southeast of river	155	280	26
17	N 1-3/4 miles south of river	154	556	1
18	U East Windsor	140	351	21
19	W East Windsor, near river	140	322	34
20	V East Windsor	140	249	21
21	S Walkerville, 2-1/2 miles southeast of river	136	238	16
22	T Sandwich East, 2-3/4 miles SE of river	134	410	30
23	B Sandwich	132	278	15
24	A Sandwich	123	259	27
25	X Tecumseh, Ontario	86	204	12
26	Y McGregor, Ontario	73	214	3
Mean, Maximum and Minimum		166	556	1

tween minimum and maximum concentration levels. This variation was greater than that existing between the means for all stations.

In both Detroit and Windsor the daily variations in particulate loading of the atmosphere at each station followed the trend of the average for all stations very closely, with those stations having the highest median or means values showing also the greatest deviations from the average. At all stations of the network, the daily variations at a particular station fluctuated in phase with the values at all other sampling stations, thus indicating the preponderant influence of prevailing weather conditions on the broad pollution pattern. This aspect of the problem is discussed in connection with the correlation of pollution levels with meteorological factors in Chapter XI.

It is beyond the scope of this chapter to present in detail the large amount of basic data available on the 1951 studies of particulate matter. The information is contained in the Technical Advisory Board Reports to the International Joint Commission(108, 103).

Metallic Elements

The total particulates of the Detroit high volume air samples collected in 1951 were weighed and analyzed spectrographically to identify quantitatively and semiquantitatively twenty-four elements. Seventy-four samples from the Windsor collection were also analyzed.

Figure VII-15 shows the percentage of the average contribution of six elements to the total weight of twenty-two elements at each sampling

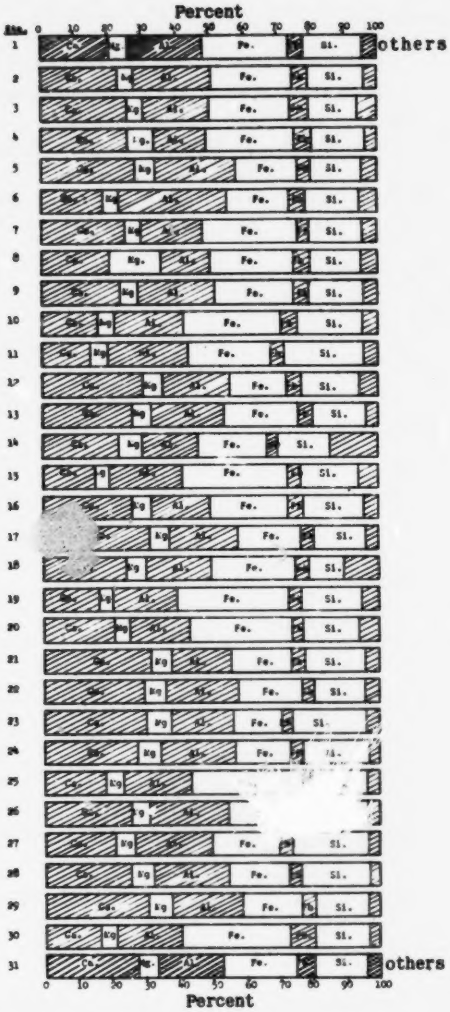


Figure VII-15. Average Contribution of Six Elements to the Total Weight of 22 Elements at Each Sampling Station in Detroit.

station in Detroit. Aluminum, iron, silicon and calcium are the most abundant. Stations 7, 15, 19, 20, 25 and 30 have a greater percentage of iron than the other stations. These areas were heavily industrialized with many of the industries working with ferrous metals. The percentage of lead in the samples was remarkably uniform throughout each of the areas with the exception of Station 30, which was slightly higher. The high lead concentration in Station 30 may be explained by the many industries using lead compounds in that area.

The concentration of magnesium, with the exception of Station 8, was also remarkably uniform throughout the thirty-one stations. The high magnesium in Station 8 may be explained as a result of the large number of casting and metal fabricating plants within the vicinity of the sampling site.

The percentage of aluminum found in the samples was uniform throughout the stations with the exception of Station 6. The high percentage of aluminum found in Station 6 might be explained by the presence of a large number of industries in the area either using aluminum as a product or by-product in their operations.

The percentage of calcium found in the samples was erratic, ranging from a high of 32 percent at Station 21 to a low of 14 percent at Station 11.

Silicon was present in relatively large amounts at all stations.

The percentage of all other constituents found in the samples at all the thirty-one stations was fairly uniform with the exception of samples from Stations 14 and 18. This deviation may be explained in the high percentage of zinc found at these stations.

Calcium, silicon, aluminum and iron were the most abundant, by far, of the elements analyzed spectrographically in the samples of particulate matter. Industrial sources of these elements in the study area are most commonly blast furnaces, iron and steel works, cement, lime and soda ash manufacturing plants. Next in order of relative abundance were magnesium, lead, zinc, manganese and copper. Sources of industry that contribute to such metallic pollutants are foundries and steel fabricating plants. A considerable fraction of the lead in the atmosphere comes from the exhaust gases of motor vehicles because tetraethyl lead is added to nearly all gasoline used in automobile engines.

In general, it was noted that the sampling stations at which the highest amounts of particulate pollutants were found also showed the highest loading in the summation of the elements noted above. Seven of the nine stations highest in lead loading were also among the first nine in total particulate matter.

The 22 elements analyzed spectrographically are contained in compounds such as oxides, carbonates, sulfates, chlorides, etc., that form the bulk of the inorganic fraction of the particulate matter. In exceptional cases, it was found that some stations of high particulate loading were rated relatively low in the total of these elements due to the preponderance of carbonaceous materials. This was especially noticeable at stations located in the vicinity of heavy coal consuming industries and railway operations.

Fluorides, Sulfates and Chlorides

Samples that were analyzed for fluorides, sulfates and chlorides in the particulate matter were selected randomly to include all stations in Detroit on seven days in May and six days in June of 1951. The samples were arranged further into five groups of two days' samples in each, and a sixth group representing three days. This was done in order to increase the weight of material available for analysis.

Fluorides

The relationship of median fluoride value to median particulate matter concentration is presented in Table VII-9. Median fluoride concentration ranged from a low of 0.019 micrograms per cubic meter of air at Station 22, to a high of 0.27 at Station 15. At many sampling stations there was fair agreement between relatively high total concentration of particulate matter and fluorides. There were, however, some notable exceptions. For example, at Stations 1 and 7 the fluoride values were the fourth and sixth highest, respectively, whereas the particulate matter concentrations ranked thirteen and sixteen in descending order. The maximum fluoride concentration found was 1.25 micrograms per cubic meter.

The presence of fluorides in the atmosphere of cities is linked in large measure to the fluorides in coal. Some of this is released in high temperature melting operations associated with production of iron and steel, from cupolas of iron foundries, in the manufacture of cement, brick, pottery and ferro-enamels, and in the aluminum and phosphate fertilizer industries.

Sulfates

The relationship of median sulfate values to total weight concentration values is shown in Table VII-10. A study of this table reveals, as in the case of fluorides, that there is some agreement between sulfates and total weight. There are, however, exceptions to this, with Stations 1 and 7 among the more notable ones. It is interesting that these are the same stations that were considered exceptional in the case of fluorides. There was a sixfold increase between the lowest median value of 0.45 micrograms per cubic meter of air at Station 22 to the highest median value of 2.65 at Station 15. Stations 15 and 19 had the highest median values for sulfates as well as for fluorides.

Table VII-9. Relationship of Fluorides to Total Particulate Matter

Micrograms per cubic meter of air

Station	T. W.[a] Median	T. W.[a] Position	Fluoride Median	Fluoride Position
15	753	1	.270	1
19	530	5	.270	2
20	560	3	.230	3
1	430	13	.195	4
14	476	8	.175	5
7	419	16	.155	6
4	632	2	.145	7
16	425	14	.145	8
2	468	10	.135	9
10	555	4	.120	10
30	421	15	.097	11
11	490	7	.090	12
6	508	6	.088	13
26	471	9	.084	14
9	362	18	.072	15
18	327	24	.070	16
24	356	20	.065	17
8	334	22	.064	18
31	462	11	.063	19
13	270	26	.061	20
3	357	19	.058	21
12	337	21	.053	22
17	455	12	.052	23
27	328	23	.051	24
5	279	25	.048	25
29	272	27	.046	26
28	266	28	.040	27
25	373	17	.039	28
21	212	31	.034	29
23	251	29	.030	30
22	227	30	.019	31

[a] Total weight. Median values of total weight of particulate matter based on data obtained the following days: May 7, 11, 13, 19, 23, 24, 27 and June 2, 4, 7, 12, 13 and 15.

Table VII-10. Relationship of Sulfates to Totals Particulate Matter

Micrograms per cubic meter of air

Station	T. W.[a] Median	T. W. Position	Sulfate Median	Sulfate Position
15	753	1	2.65	1
19	530	5	2.59	2
14	476	8	1.80	3
1	430	13	1.77	4
7	419	16	1.70	5
4	632	2	1.43	6
30	421	15	1.42	7
20	560	3	1.40	8
10	555	4	1.40	9
16	425	14	1.37	10
2	468	10	1.27	11
6	508	6	1.24	12
26	471	9	1.18	13
11	490	7	1.15	14
8	334	22	1.04	15
13	270	26	0.98	16
9	362	18	0.95	17
3	357	19	0.89	18
17	455	12	0.82	19
31	462	11	0.81	20
27	328	23	0.76	21
25	373	17	0.74	22
12	337	21	0.68	23
24	356	20	0.67	24
18	327	24	0.65	25
5	279	25	0.65	26
29	272	27	0.58	27
28	266	28	0.56	28
23	251	29	0.52	29
21	212	31	0.51	30
22	227	30	0.45	31

[a] Total weight. Median values of total weight of particulate matter based on data obtained the following days: May 7, 11, 13, 19, 23, 24, 27 and June 2, 4, 7, 12, 13 and 15.

The highest value for sulfates was 3.73 and the lowest 0.12 micrograms per cubic meter. Levels of sulfate in particulates are on the average ten times or more greater than corresponding values for fluorides. The major source of sulfate is from the sulfur dioxide produced in combustion of fuels.

Chlorides

The relationship of median values of chlorides to median values of total weight concentration is shown in Table VII-11. It may be noted that, as in the case of fluorides and sulfates, Stations 19 and 15 were also highest in chlorides. For the data at most of the stations, however, there is little, if any, correlation between chlorides and total weight. There was approximately an eightfold increase from the low median value of 0.23 micrograms per cubic meter of air at Station 23, to the highest median value of 1.79

Table VII-11. Relationship of Chlorides to Total Particulate Matter

Micrograms per cubic meter of air

Station	T. W.[a] Median	T. W.[a] Position	Chloride Median	Chloride Position
19	530	5	1.79	1
15	753	1	1.68	2
8	334	22	1.37	3
4	632	2	1.22	4
7	419	16	1.21	5
9	362	18	1.18	6
1	430	13	1.18	7
26	471	9	1.18	8
2	468	10	1.13	9
13	270	26	1.13	10
14	476	8	1.12	11
31	462	11	1.07	12
20	560	3	0.98	13
3	357	19	0.93	14
25	373	17	0.86	15
30	421	15	0.85	16
16	425	14	0.84	17
18	327	24	0.79	18
6	508	6	0.78	19
10	555	4	0.77	20
11	490	7	0.76	21
21	212	31	0.66	22
17	455	12	0.56	23
22	227	30	0.53	24
24	356	20	0.53	25
5	279	25	0.52	26
12	337	21	0.43	27
28	266	28	0.42	28
29	272	27	0.41	29
27	328	23	0.39	30
23	251	29	0.23	31

[a] Total weight. Median values of total weight of particulate matter based on data obtained the following days: May 7, 11, 13, 19, 23, 24, 27 and June 2, 4, 7, 12, 13 and 15.

micrograms per cubic meter of air at Station 19. The maximum chloride value was 5.46. Median concentrations of chlorides at all stations were intermediate between the levels of sulfates and fluorides.

Gaseous Fluorides and Chlorides

It is apparent that only particulate fluorides and chlorides are present in the material collected by filtration with the high volume air sampler. To obtain data on the relative amounts of volatile fluorides and chlorides present in the Detroit atmosphere, samples for these compounds were collected also with the standard impinger. The results are shown in Table VII-12.

The average value for chlorides collected by the standard impinger was approximately six

Table VII-12. Relationship of Chloride and Fluoride Values Obtained with the Standard Impinger to Chloride and Fluoride Values Obtained with the High Volume Air Sampler

All Values are given in Micrograms per Cubic Meter of Air

	Chlorides				Fluorides			
Station No.	Filter Paper Samples Average	Impinger Samples[a]	No. of Impinger Samples	No. of Filter Paper Samples	Filter Paper Samples Average	Impinger Samples[a]	No. of Impinger Samples	No. of Filter Paper Samples
1	1.34	8.82	2	6	0.17	0.15	2	6
2	1.41	2.94	1	5	0.13	0.39	1	5
3	0.80	.....	0	6	0.09	2.45	1	6
4	1.32	.....	0	6	0.15	0.86	2	6
5	0.95	5.88	1	6	0.07	1.51	3	6
6	1.01	10.13	2	6	0.09	0.10	1	6
7	1.29	7.84	3	6	0.17	0.57	4	6
8	1.24	5.88	1	6	0.08	0.10	1	6
9	1.21	2.94	1	6	0.07	2.42	2	6
10	1.12	11.90	1	6	0.11	0.68	1	6
11	1.11	2.94	1	6	0.11	0.38	1	6
12	0.39	.....	0	5	0.06	1.21	2	5
13	1.00	2.94	2	6	0 07	0.29	2	6
14	1.09	.....	0	6	0.24	....	0	6
15	1.74	5.88	2	6	0.27	1.04	3	6
16	1.02	17.64	1	6	0.17	0.00	1	6
17	0.85	2.65	2	6	0.10	1.61	2	6
18	0.71	.....	0	6	0.07	3.47	1	6
19	2.18	5.88	1	6	0.40	0.50	2	6
20	1.36	4.83	1	6	0.27	2.84	2	6
21	0.92	.....	0	5	0.08	....	0	5
22	0.69	.....	0	6	0.07	....	0	6
23	0.46	2.94	2	6	0.09	0.10	2	6
24	0.69	2.94	2	6	0.11	0.24	2	6
25	0.91	8.82	1	5	0.06	0.10	1	5
26	1.53	.....	0	6	0.10	0.10	1	6
27	0.39	3.45	2	6	0.05	0.00	1	6
28	0.53	7.35	2	6	0.05	0.10	1	6
29	0.51	.....	0	6	0.05	....	0	6
30	1.08	.....	0	5	0.13	1.94	2	5
31	1.18	2.94	1	6	0.09	0.46	3	6
Average	1.03	6.07			Av. 0.12	0.87		

[a] Where more than one sample is indicated, the average value of the samples is reported.

times the average for samples collected by filtration with high volume air samplers. In the case of fluorides the mean values for the two types of samples differed by a factor of about seven. Gaseous or volatile fluorides and chlorides are therefore present in the atmosphere, on the average, to a far greater extent than the corresponding solid phases.

Studies of Aerosol Pollutants in 1952

In 1952, from August 7 through September 19, a joint six-week study of particulate pollutants was made in the Detroit-Windsor area during which simultaneous samples were collected with high volume samplers at nine Detroit and ten Windsor sampling stations. After determination of the weight concentration, the particulate samples were analyzed by spectrographic methods for 22 metallic elements. Evaluation of the data yielded interesting comparisons on the relative particulate loading of the atmosphere in Detroit and Windsor and on the distribution of the various elements. A comparison was made of Windsor and Detroit particulates collected on a day of high pollution and a day of low pollution, and of samples collected on Sundays and Wednesdays.

During the study the air loadings of particulates varied for Detroit from a maximum of 719.5 micrograms per cubic meter to a minimum of 33.1. The median values by stations varied from 401.7 to 170.8 micrograms per cubic meter. For Windsor the maximum and minimum values were 718.0 and 3.2 respectively, and the median values ranged from 281.2 to 103.5. The median, minimum and maximum values for each station are shown in Table VII-13.

The distribution by total weight of the samples collected at the 19 stations is shown in Table VII-14. Of 242 Detroit samples, 81% fall between 100 and 500 micrograms per cubic meter, with the others almost equally divided, 10% below 100, 9% above 500 micrograms. Of 314 Windsor samples, 73% fall between the same limits, but in this case 23% fall below the 100 microgram level. However, 85% fall between the 50 and 400 microgram levels, with a fairly even distribution of 7% below the 50, and 8% above the 400 level.

The variation in mass concentration of the 22 elements in the particulate samples is shown in Table VII-15. For most of these elements the values are higher at Windsor than at Detroit sampling stations. Since the Detroit atmosphere contains the heavier leading in particulate matter, it must be evident that the inorganic fraction of particulate matter in Windsor represents a higher proportion of the aerosol pollutants than in Detroit. Conversely, in the Detroit samples there is apparently a higher percentage of carbonaceous or organic matter.

Median and maximum values for calcium, silicon, iron and magnesium are considerably

Table VII-13. Total Particulate Matter at Nine Stations in Detroit and Ten Stations in Windsor - August 7 through September 19, 1952

Position	DETROIT				WINDSOR			
	Station	Median	Minimum	Maximum	Station	Median	Minimum	Maximum
		Micrograms per cubic meter of air				Micrograms per cubic meter of air		
1	15	401.7	82.1	719.5	2	281.2	27.3	587.8
2	19	382.0	133.3	647.4	4	251.0	56.0	718.0
3	4	360.4	171.2	565.1	3	250.4	47.0	546.8
4	11	277.0	62.0	467.9	5	207.0	35.4	503.0
5	1	268.7	112.6	529.7	1	191.2	49.2	538.0
6	12	192.7	33.1	652.5	8	173.8	36.1	568.2
7	25	189.2	99.8	586.0	10	146.0	42.1	394.5
8	28	181.2	33.1	507.1	7	140.7	21.7	547.8
9	24	170.8	52.7	544.7	9	120.3	5.8	256.7
10	-	-	-	-	6	103.5	3.2	223.9

Table VII-14. Frequency Distribution of Total Particulate Matter Collected at Nine Stations in Detroit and Ten Stations in Windsor - August 7 through September 19, 1952

Particulate matter Micrograms per cubic meter of air	Detroit Stations									Windsor Stations									
	1	4	11	12	15	19	24	25	28	1	2	3	4	5	6	7	8	9	10
0.0 - 50.0	-	-	-	-	-	-	-	-	1	1	1	1	-	1	4	3	2	4	3
50.1 - 100.0	-	-	2	6	1	-	7	1	6	5	2	4	3	4	8	9	5	7	6
100.1 - 150.0	2	-	4	7	-	2	7	2	6	6	1	1	6	5	7	10	6	3	10
150.1 - 200.0	3	4	1	6	1	1	6	8	9	13	3	5	1	3	5	10	5	7	6
200.1 - 250.0	2	2	2	4	2	1	3	3	5	5	5	4	4	9	2	5	3	1	5
250.1 - 300.0	6	1	3	5	3	3	2	1	5	2	8	4	2	2	-	2	3	1	2
300.1 - 350.0	3	3	1	2	1	3	8	-	3	5	5	4	2	1	-	1	-	-	-
350.1 - 400.0	1	3	5	4	2	4	3	1	-	2	3	3	2	-	-	-	2	-	3
400.1 - 450.0	1	3	2	1	6	5	-	-	-	1	-	2	3	3	-	-	1	-	-
450.1 - 500.0	1	3	2	-	-	1	1	-	-	-	2	1	2	-	-	-	-	-	-
500.1 - 550.1	2	1	-	-	1	3	2	2	1	2	-	1	-	1	-	1	-	-	-
550.1 - 600.0	-	1	-	1	1	-	-	1	-	-	2	-	-	-	-	-	1	-	-
600.1 - 650.0	-	-	-	-	2	2	-	-	-	-	-	-	1	-	-	-	-	-	-
650.1 - 700.0	-	-	-	1	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
700.1 - 750.0	-	-	-	-	1	-	-	-	-	-	-	-	1	-	-	-	-	-	-
Total number of samples	21	21	22	38	21	25	39	19	36	42	32	30	28	29	26	41	28	23	35

Table VII-15. Twenty-two Elements Determined Spectrographically from Samples Collected at 9 Stations in Detroit and 10 Stations in Windsor - August 7 through September 19, 1952

Elements	DETROIT			WINDSOR		
	Median	Minimum	Maximum	Median	Minimum	Maximum
	Micrograms per cubic meter of air					
Calcium	11.1	1.0	21.1	28.4	1.3	130.6
Aluminum	3.6	0.4	29.8	5.7	0.52	32.5
Iron	2.4	trace	15.6	5.75	0.52	24.7
Silicon	1.7	0.3	10.6	7.8	0.44	70.3
Magnesium	0.9	0.3	4.5	2.3	0.2	14.1
Lead	0.4	0.01	1.6	0.5	0.03	3.1
Zinc	0.2	absent	1.5	0.08	absent	1.5
Manganese	0.2	0.03	0.5	0.27	0.02	1.2
Copper	0.08	absent	1.2	0.18	0.02	0.84
Titanium	0.06	absent	1.5	0.25	0.036	0.82
Tin	0.04	trace	0.08	0.044	0.003	0.28
Molybdenum	0.04	trace	0.09	0.07	0.008	0.26
Barium	0.02	trace	0.04	0.01	0.01	0.16
Chromium	0.02	trace	0.3	0.017	0.017	0.30
Bismuth	0.02	absent	0.04	absent	absent	absent
Nickel	0.009	absent	0.03	0.017	0.002	0.10
Tungsten	0.009	absent	0.3	0.03	absent	0.22
Vanadium.	0.008	absent	0.02	0.022	absent	0.12
Antimony	trace	absent	0.03	0.04	absent	0.13
Cadmium	trace	absent	0.04	trace	absent	0.04
Cobalt	absent	absent	0.004	absent	absent	0.02
Beryllium	absent	absent	0.01	absent	absent	0.012

higher in the Windsor atmosphere than in the Detroit atmosphere. Aluminum, lead and manganese values are also somewhat higher in Windsor. The median concentration of zinc is greater in Detroit. Most of the elements in samples from both cities show a considerable range of concentration from minimum to maximum values. This degree of variation is not unusual for material collected under a considerable range of weather conditions over a period of six weeks in an area-wide sampling network.

Comparison of Sundays and Wednesdays

A comparison was made of the relative differences in weight concentration of particulates and in the content of six common elements in samples collected on Sundays and Wednesdays at three stations in Detroit and at three stations in Windsor. The data are shown in Table VII-16 and are plotted graphically, with the elements of particulate matter, in Figures VII-16 and VII-17.

At each station the average weight concentration of aerosol pollutants was greater on Wednesdays than on Sundays, indicating agreement with the general concept of an increase in industrial activity and, consequently, in emission products on a week day. However, the total concentration of elements in the Detroit samples did not show a proportionate increase on Wednesdays over Sundays. On a percentage basis, the elements in the midweek Detroit samples were much below the corresponding percentage values for Sundays. For the Windsor samples, on the other hand, the midweek increase in total weight of particulates was accompanied by a roughly proportional rise in the content of metallic elements. At two of the Windsor sampling stations, the percentages of total elements actually showed an increase on Wednesday over Sunday. In other words, a large proportion of the midweek increase in pollution loading at Detroit must be due to organics, probably from the incomplete combustion of fuels from power and industrial plants and from transportation and vehicular traffic sources. In Windsor the relatively unaltered percentage composition of the pollution complex underlines a much smaller degree of industrialization.

Table VII-16. Comparison of Samples Collected on Sundays and Wednesdays at Three Stations in Detroit and Windsor - August 7 through September 19, 1952

Day	Station	Samples	Micrograms per cubic meter of air								
			Average Total Weight	Ca	Mg	Al	Fe	Pb	Si	All Others	Average Total Elements
DETROIT											
Sunday. . . .	12	4	118.2	12.62	0.81	2.03	1.25	0.37	3.24	0.29	20.62
Wednesday .	12	7	282.3	9.95	0.98	4.77	3.93	0.57	2.34	0.78	23.32
Sunday. . . .	24	5	130.8	9.75	0.76	3.00	1.22	0.23	3.21	0.41	18.59
Wednesday .	24	5	268.7	9.77	1.13	5.43	1.88	0.61	2.38	0.62	21.82
Sunday. . . .	28	3	133.6	8.87	0.58	2.73	0.40	0.20	1.91	0.32	15.03
Wednesday .	28	7	178.3	9.44	0.97	3.05	1.72	0.25	1.34	0.31	17.09
WINDSOR											
Sunday. . . .	1	6	153.1	18.10	1.40	4.55	4.60	0.35	3.45	0.85	33.30
Wednesday .	1	6	198.7	16.60	1.15	5.05	5.55	0.49	9.05	1.52	39.41
Sunday. . . .	7	6	111.5	7.60	1.00	3.00	2.60	0.20	5.20	0.67	20.27
Wednesday .	7	5	162.7	25.60	1.75	5.85	6.20	0.23	9.25	0.91	49.79
Sunday. . . .	10	1	80.4	6.10	0.70	2.00	2.00	0.11	4.90	0.43	16.28
Wednesday .	10	3	225.0	11.00	1.30	5.60	5.60	0.60	17.60	1.76	

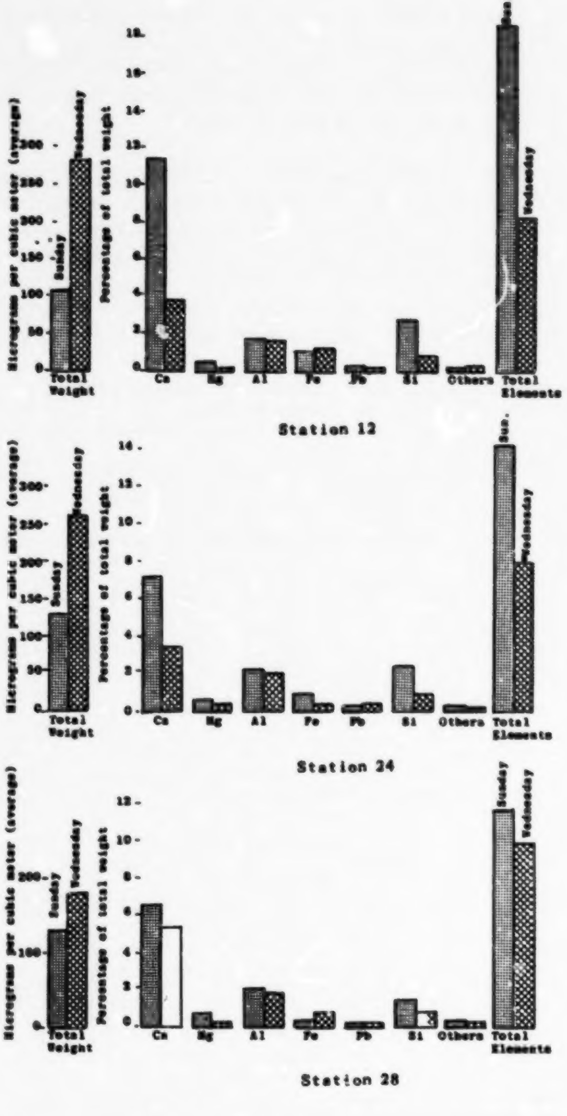


Figure VII-16. Comparison of Average Total Weight and Six Elements in Particulate Matter Collected on Sundays and Wednesdays at Three Windsor Sampling Stations - For Stations 12, 24, and 28.

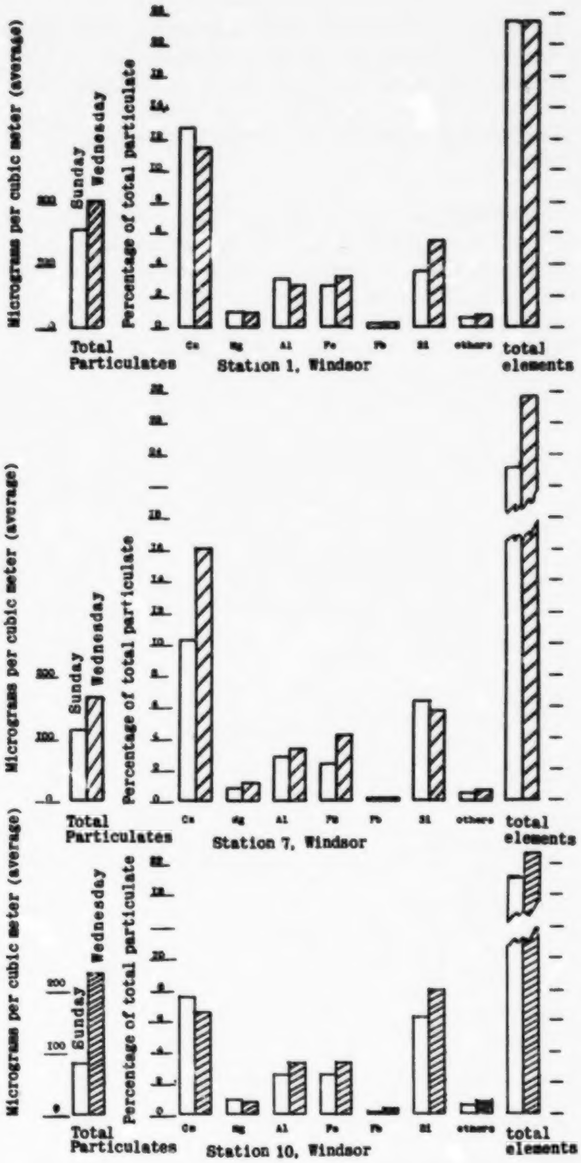


Figure VII-17. Comparison of Average Total Weight and Six Elements in Particulate Matter Collected on Sundays and Wednesdays at Three Windsor Sampling Stations - For Stations [illegible], 7 and 10.

During weekends, most of the industrial or fixed sources of emission cease operations or curtail activities considerably. Traffic, however, takes new routes, leaving busy weekday routes comparatively free and crowding highways leading out of the city.

Comparison of Heavy and Light Pollution Days

A comparison of the particulate loading on a day (11 September, 1952) of heavy and on a day

(22 August, 1952) of light pollution was made from the analytical data of samples taken at four Detroit and eight Windsor stations. A tabulation of the weights and ratios for total loading and also for six common elements is given in Table VII-17.

As expected, total loadings were consistently higher at all stations for the heavy pollution day (11 September). Comparison disclosed, however, that in the Detroit samples the ratios for calcium, magnesium, and aluminum are generally below the weight ratio, usually less than one. In the Windsor samples, the ratios for these elements are generally greater than the total weight ratios. In the case of silicon, the Detroit ratio is close to the weight ratio, while in Windsor it is considerably greater for all but one station. On the other hand, lead ratios run from one-half to three times the weight ratios for the Detroit stations and from one-half to seven times the weight ratios for Windsor stations.

The calcium, magnesium, aluminum, and silicon comparisons fit in very well with the fact that Detroit is a large urban area compared to the essentially fringe strip of urban Windsor. The very inversion conditions which favor a build-up of pollution would, by virtue of lower air speeds and diminished turbulence, reduce

Table VII-17. Comparison of Samples Collected at Four Stations in Detroit and Eight Stations in Windsor on a Day of Heavy (September 11, 1952) and on a Day of Light (August 22, 1952) Particulate Pollution

DETROIT

	Station 1			Station 4			Station 19			Station 24		
	Aug. 22	Sep. 11	Ratio[b]	Aug. 22	Sep. 11	Ratio[b]	Aug. 22	Sep. 11	Ratio[b]	Aug. 22	Sep. 11	Ratio[b]
Total Weight[a] . . .	182.7	529.7	2.9	186.7	419.1	2.2	140.8	620.9	4.4	60.6	538.7	8.9
Calcium	10.97	2.01	0.18	14.53	6.72	0.46	6.51	5.68	0.87	14.26	7.28	0.51
Magnesium.	3.29	1.08	0.33	2.18	1.01	0.46	0.75	1.02	1.46	0.68	1.64	2.41
Aluminum	10.97	6.02	0.55	10.90	6.72	0.62	3.25	2.84	0.87	2.25	7.28	3.24
Iron	1.73	6.02	3.40	2.72	6.72	2.40	2.44	3.79	1.60	1.36	2.73	2.00
Lead	0.08	0.80	10.00	0.18	0.67	3.70	0.10	0.47	4.70	0.18	0.73	4.10
Silicon	1.65	4.82	2.90	1.09	2.02	1.90	0.88	4.54	5.10	0.82	4.37	5.30
All Others	0.39	1.57	4.00	0.54	1.58	2.90	0.48	1.15	2.30	0.27	0.88	3.30
Total 22 elements	29.38	22.32	0.74	32.14	25.43	0.79	14.32	19.49	1.36	19.65	24.91	1.27

WINDSOR

	Station 1			Station 2			Station 3			Station 4		
Total Weight[a] . . .	73.6	538.0	7.3	58.0	573.9	9.9	51.5	409.8	8.0	66.9	661.0	9.9
Calcium.	21.90	29.50	1.34	8.24	43.20	5.25	7.40	64.70	8.75	10.50	87.80	8.35
Magnesium.	1.00	4.40	4.40	0.30	5.70	19.00	0.30	12.90	43.00	0.42	12.60	30.00
Aluminum	2.10	14.70	7.00	1.40	21.60	15.40	1.40	13.60	9.70	1.30	29.30	22.55
Iron	2.80	9.30	3.30	1.70	13.60	8.00	1.40	8.20	5.85	1.60	13.90	8.70
Lead	0.30	1.90	6.30	0.20	1.10	5.50	0.10	0.60	6.00	0.10	0.39	3.90
Silicon.	3.30	35.30	10.70	4.95	38.90	7.85	3.33	38.70	11.60	3.20	70.30	22.00
All Others	0.75	2.77	3.70	0.38	2.85	7.50	0.39	2.05	5.25	0.57	2.94	5.15
Total 22 elements	32.15	97.87	3.04	17.17	126.95	7.40	14.32	140.75	9.80	17.69	217.23	12.30

	Station 5			Station 7			Station 8			Station 10		
Total Weight[a] . . .	35.4	322.9	9.1	88.2	547.8	6.2	36.1	568.2	15.7	42.2	380.7	9.0
Calcium.	7.08	105.50	14.90	7.50	130.00	17.35	7.80	120.0	15.40	2.20	42.00	19.10
Magnesium.	0.40	12.00	30.00	0.70	7.40	10.55	0.20	12.00	60.00	0.35	5.50	15.70
Aluminum	0.90	16.70	18.55	2.80	32.50	11.60	0.75	30.10	40.10	1.10	18.50	16.80
Iron	0.90	10.00	11.10	1.90	24.70	13.00	0.52	15.20	29.20	0.86	13.30	15.50
Lead	0.05	0.70	14.00	0.04	1.70	42.50	0.10	2.10	21.00	0.06	2.10	35.00
Silicon.	1.10	23.70	21.55	4.50	39.00	8.65	0.44	47.90	108.90	0.68	50.30	74.00
All Others	0.19	1.80	9.45	1.11	5.63	5.05	0.15	1.57	10.45	0.29	3.08	10.60
Total 22 Elements	10.62	170.40	16.00	29.17	240.93	8.25	9.96	228.87	23.00	5.54	134.78	24.30

[a] Weight of sample in micrograms per cubic meter of air. [b] Ratio of material collected on September 11, 1952 to August 22, 1952.

the extent of wind blown dust from rural areas and also re-entrainment of urban fall-out. This would result, in Detroit, in a perferential reduction of the main constituents of rural pick-up, as compared to the particulate pollutants supplied by urban sources. Windsor as a fringe or ribbon of urban development received the spreading, inversion-trapped cloud of dust resulting from immediately contiguous rural as well as industrial activity. This cloud which normally would be undergoing vertical mixing would, under inversion conditions, remain in suspension long enough to weight significantly the Windsor air samples.

The lead figures follow a different pattern. Lead is largely a city-produced pollutant, ordinarily emitted to the air from automobile exhausts, lead and base-metal foundries, refineries, battery salvage operations, paint manufacture, and gasoline storage.

The lead concentration at any point will depend on the magnitude and duration of all of these activities, as well as their locations in relation to sampling stations and ventilation of the area. The fact that the Windsor range of lead ratios is greater than the Detroit range can probably be ascribed to the small extent of the Windsor urban strip and closer proximity of sampling stations to traffic and industrial sources.

For the day (22 August) of light particulate pollution the total of the 22 elements represented about 10 to 17 percent of the total weight of particulate matter at three of the Detroit sampling stations and about 32 percent at the fourth station. These percentages decreased on the day of heavy pollution to such an extent that the sum of the 22 elements amounted to only about 3 to 6 percent of the total weight of air-borne particulates. This was due, no doubt, to the corresponding rise in the organic fraction of pollutants.

At the eight Windsor stations, these elements represented a much higher proportion of the total weight of the dust. For the day of light pollution the fractions comprising the 22 elements amounted to about 13 to 36 percent at the various sampling stations. This proportion increased to approximately 18 to 53 percent on the day of heavy pollution. It may be concluded that community activities in Windsor differ considerably from those in Detroit, especially in regard to the proportion of inorganic to organic material discharged to the air directly or indirectly from such activities.

Air-borne Versus Soil Particles

A study was made to evaluate the relationship of the elements found in air-borne dust samples to the elements contained in the surface soil. It was hoped to determine the differences in distribution of certain elements in those contaminants that are discharged initially to the atmosphere by industrial and community sources, to those being redispersed from the soil into the atmosphere as the result of wind movement. The air-borne samples were collected by means of high volume samplers during the period August 7 through September 19, 1952. Soil samples were obtained by removing 1/2 inch of the top soil over an area of one-foot square in the vicintiy of the air sampling station, mixing the material thoroughly and taking representative sample for analysis.

The analytical data for 22 elements in the samples from three Detroit and six Windsor stations are given in Tables VII-18 and VII-19, respectively. Most of the elements are present in varying amounts in both air-borne and soil particles. The major fraction consists of calcium, aluminum, iron and silicon. At all stations, the combined total amount of calcium, aluminum and iron is greater in the air-borne particulates than in the soil samples. The content of magnesium is noticeable higher in the air-borne samples (with one exception). Silicon, which is one of the major soil-forming elements, is higher in the surface soil at five of the Windsor stations, and is almost identical in quantity in both air-borne and surface samples from one of the Detroit and one of the Windsor stations.

The above five elements compose approximately 95 percent of the weight of the 22 elements in both air-borne and soil samples at all these sampling stations. More substantial differences in composition are found in the relative content of heavy metals, especially lead and zinc. The latter are not normal constituents of surface soil material and occur in the atmosphere after discharge from industrial and other sources as fumes which form finely divided aerosols. The air-borne samples contained relatively much higher amounts of both lead and zinc than the soil samples. It is probable, in fact, that the small amounts of these heavy metals found in

Table VII-18. **Relationship of 22 Elements in Air-borne Samples to Top Soil Samples at Three Stations in Detroit**

MILLIGRAMS PER GRAM OF SAMPLE

Elements	Station 12		Station 4		Station 24	
	Air	Soil	Air	Soil	Air	Soil
Calcium	62.73	19.77	45.23	15.98	67.54	9.97
Aluminum	23.52	9.89	40.05	14.98	29.62	7.48
Iron	16.72	0.79	25.60	12.58	10.78	6.24
Silicon	13.73	5.93	12.34	11.99	17.25	8.97
Magnesium	5.07	2.37	8.50	3.00	6.40	1.60
Lead	2.81	0.26	3.08	0.50	2.61	nd
Zinc	1.11	tr	2.29	0.26	0.90	nd
Manganese	1.11	0.59	0.81	0.40	1.11	0.30
Titanium	0.42	0.26	0.33	0.12	0.29	0.50
Copper	0.35	nd	0.63	tr	0.67	nd
Tungsten	0.20	0.10	0.15	tr	0.10	0.06
Tin	0.18	0.08	0.18	0.10	0.17	0.02
Chromium	0.16	tr	0.04	0.06	0.02	tr
Molybdenum	0.15	0.06	0.15	0.10	0.12	tr
Bismuth	0.06	tr	0.07	tr	0.01	nd
Barium	0.06	0.16	0.07	0.16	0.07	tr
Nickel	0.04	0.02	0.04	0.20	0.05	0.10
Antimony	0.01	nd	0.01	0.06	0.01	nd
Cadmium	0.01	tr	0.008	tr	nd	nd
Vanadium	0.01	nd	0.04	tr	0.07	nd
Beryllium	0.001	nd	0.001	nd	0.01	nd
Cobalt	0.001	nd	0.001	nd	nd	nd

Note: tr - trace; nd - not detected

Table VII-19. **Relationship of 22 Elements in Airborne Samples to Top Soil Samples at Six Stations in Windsor**

MILLIGRAMS PER GRAM OF SAMPLE

Elements	Station 1		Station 6		Station 7		Station 8		Station 9		Station 10	
	Air	Soil	Air	Soil	Air	Soil	Air	Soil	Air	Soil	Air	Soil
Calcium	48.90	23.10	43.15	44.10	53.00	6.60	69.60	18.80	39.05	22.90	29.30	29.40
Aluminum	13.45	5.75	7.80	5.60	12.15	3.70	7.95	9.30	16.55	5.70	14.95	5.90
Iron	15.65	3.85	7.80	3.75	13.85	2.80	7.95	3.20	10.40	3.80	14.10	4.50
Silicon	13.70	18.50	10.20	11.00	13.85	26.30	9.35	18.80	23.50	22.90	3.33	7.00
Magnesium	4.25	1.60	2.88	2.80	4.15	0.63	3.00	2.00	6.80	2.20	3.35	2.20
Lead	1.60	nd	0.50	0.06	0.50	nd	0.80	nd	0.65	nd	1.60	nd
Zinc	0.51	nd	nd	nd	tr	nd	0.074	nd	0.146	nd	0.059	nd
Manganese	0.10	0.03	0.022	0.10	0.137	0.08	0.089	0.12	0.182	0.16	0.10	0.22
Titanium	0.13	0.16	0.041	0.28	0.165	2.80	0.054	0.26	0.125	0.38	0.096	0.28
Copper	0.076	0.10	0.033	0.10	0.062	0.06	0.085	0.06	0.11	0.10	0.092	0.055
Tungsten	0.02	nd	0.002	0.10	0.034	0.12	nd	0.04	0.019	0.06	0.027	0.04
Tin	0.025	0.01	0.003	0.01	0.027	0.008	0.016	0.006	0.032	nd	0.027	nd
Chromium	0.015	tr	0.004	0.10	0.014	0.008	0.005	0.006	0.007	0.01	0.009	0.006
Molybdenum	0.036	0.06	0.115	0.06	0.055	0.05	0.015	0.043	0.023	0.05	0.027	0.04
Bismuth	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Barium	0.005	nd	0.001	0.01	0.014	0.02	0.003	0.006	0.007	0.01	0.009	0.006
Nickel	0.0100	0.01	0.025	0.01	0.010	0.001	0.006	0.006	0.008	0.001	0.009	0.006
Antimony	0.020	tr	0.002	tr	0.02	tr	0.004	tr	0.013	tr	0.014	tr
Cadmium	tr	tr	tr	0.01	tr	tr	0.003	tr	tr	tr	0.002	tr
Vanadium	0.015	0.01	0.001	0.06	0.013	0.06	0.004	0.025	0.018	0.06	0.004	0.02
Beryllium	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
Cobalt	tr	nd	nd	tr	nd	tr	nd	nd	0.007	tr	nd	tr

Note: tr - trace; nd - not detected

the soil samples at some of the stations represent material that had been deposited from the air by fall-out. Most of the Windsor soil samples showed no detectable amounts of lead and zinc.

The remaining heavy metals comprise only a small fraction of the total weight of the 22 elements. In the Detroit samples there is evidence that they occur in greater abundance in air-borne material than in soil. No definite conclusion can be drawn for the Windsor samples, however, because the values for heavy metals below zinc in the Table for both air-borne and soil material are so low as to render it doubtful if valid comparisons can be made on a quantitative basis.

Other aspects of the studies on concentration and composition of particulate matter in 1951 and 1952 are beyond the scope of this Report and have been presented in Progress Reports to the International Joint Commission(109, 104).

Daily and Mean air-borne Particulate Loadings

A considerable amount of information was accumulated on the daily fluctuations in air-borne particulate loadings or concentrations at four stations on the Canadian side and at four stations on the United States side of the study area during the period, July 1953 through December 1955. These sampling stations were located in the vicinity of the households involved in the Health Study, in areas of relatively high and low pollution. On weekdays, samples of particulates were collected over each period of 24 hours, but a 72-hour sample was collected during weekends.

The data on the daily fluctuations at the Windsor high pollution area (Ambassador Park or Peter and Chappell Sts.), Windsor low pollution area (Riverside and Lauzon) and the control area (country town of Harrow) are shown graphically in Figures VII-18 to VII-25, inclusive. In general, these daily levels of air-borne particulate pollution over the 2-1/2-year period reflect the influence of prevailing meteorological factors and seasonal trends. The maximum and

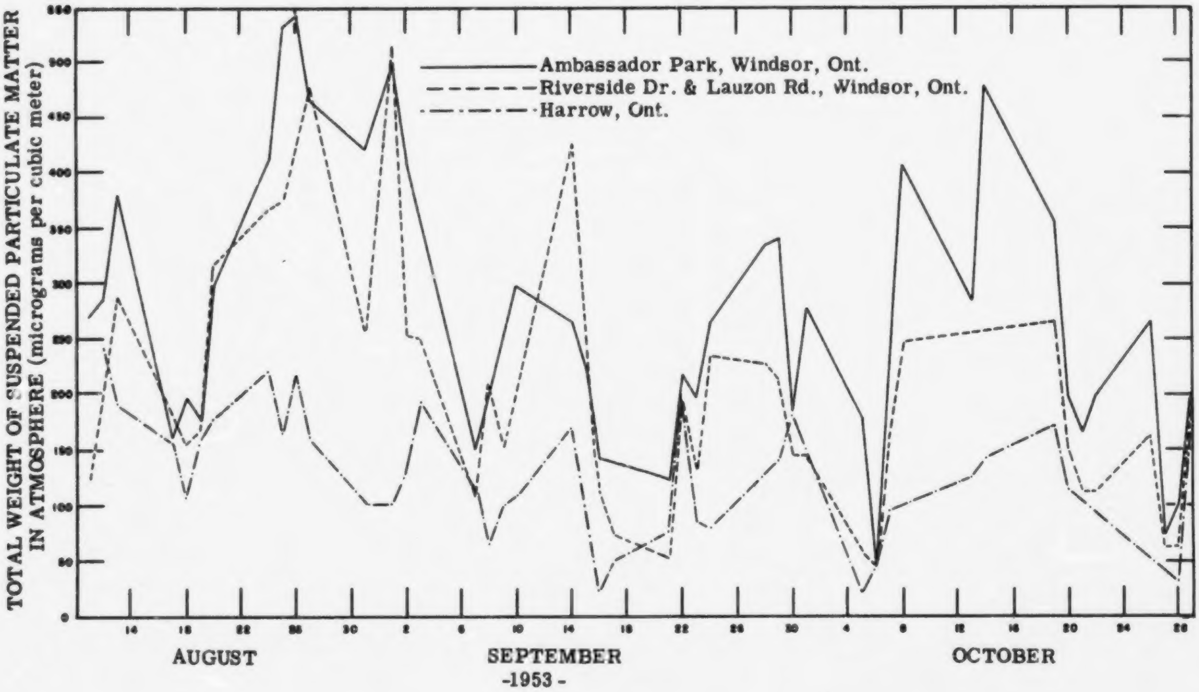


Figure VII-18. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, August through October, 1953.

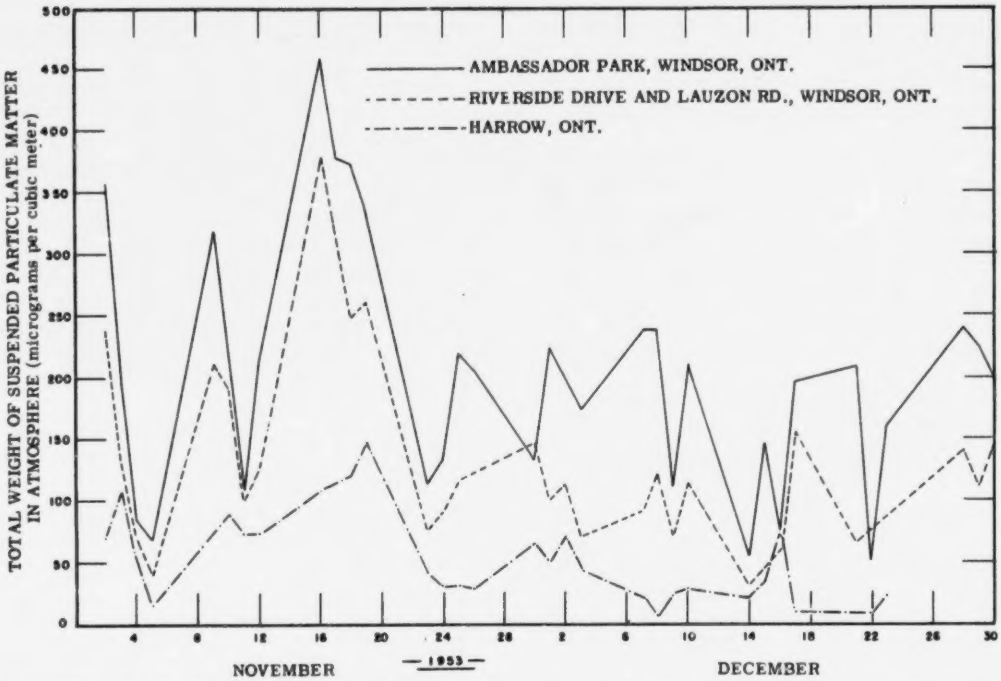


Figure VII-19. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Area, November and December, 1953

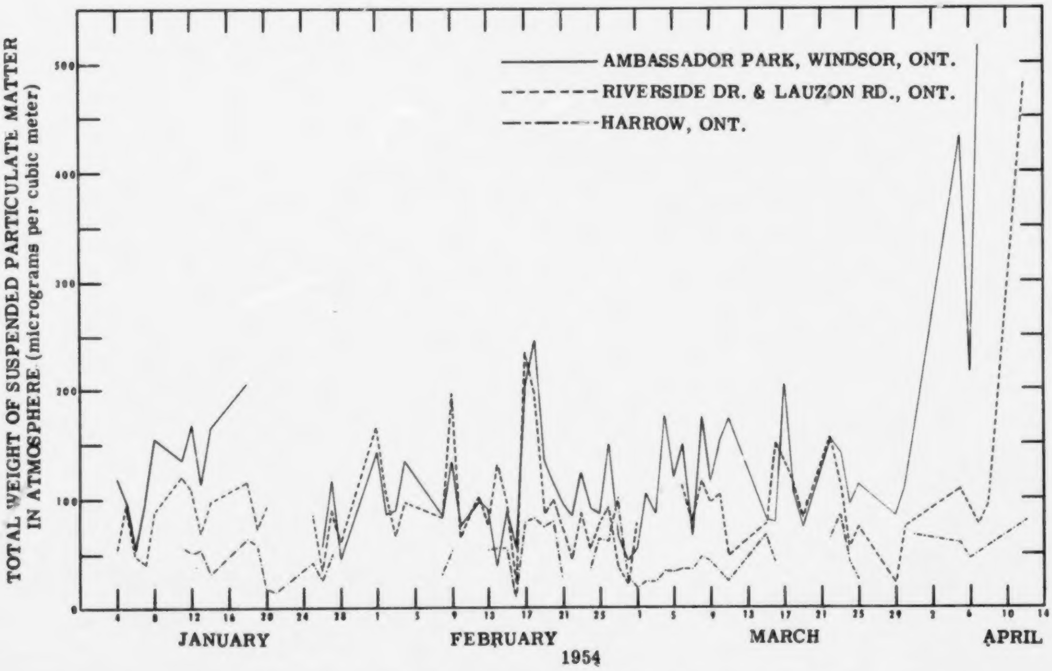


Figure VII-20. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, January through April, 1954

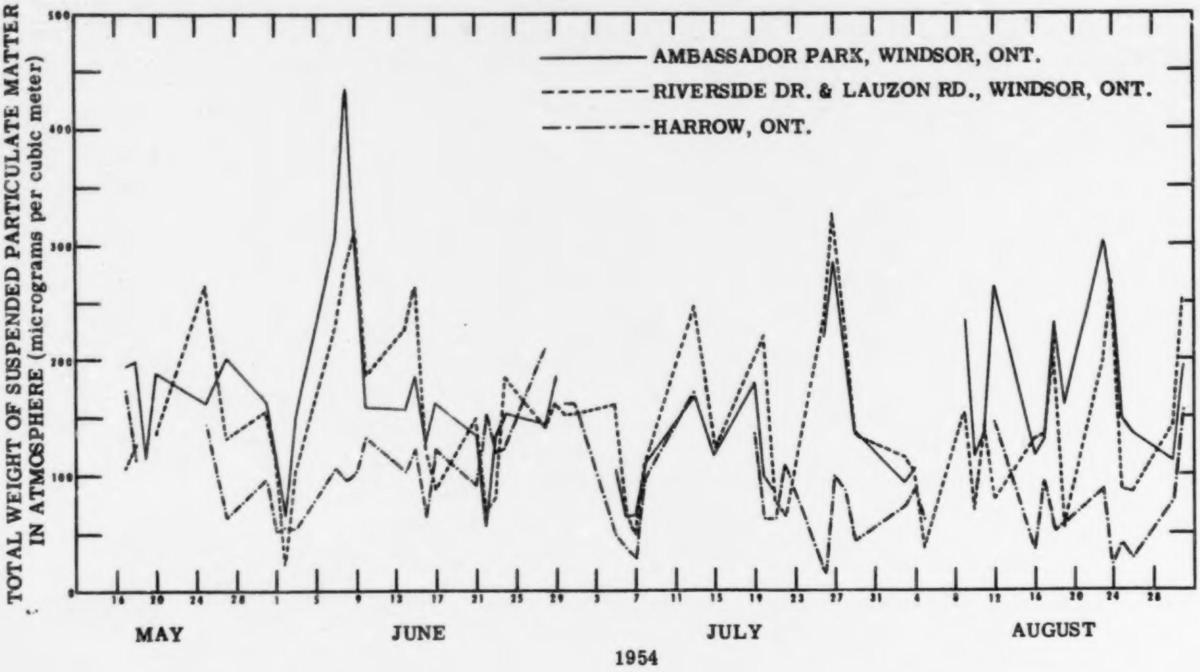


Figure VII-21. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, May through August, 1954.

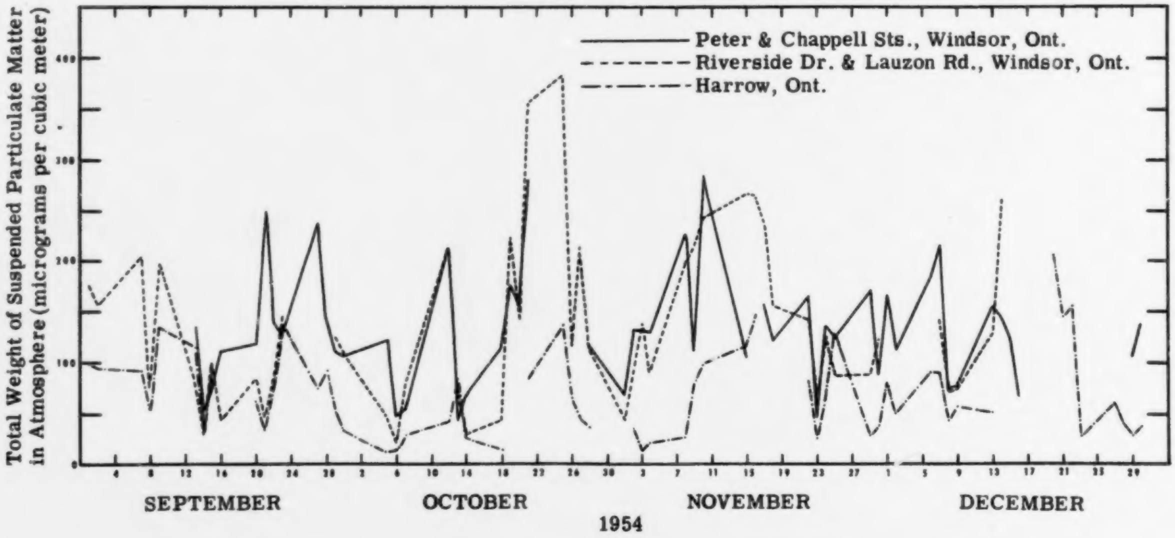


Figure VII-22. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, September through December, 1954.

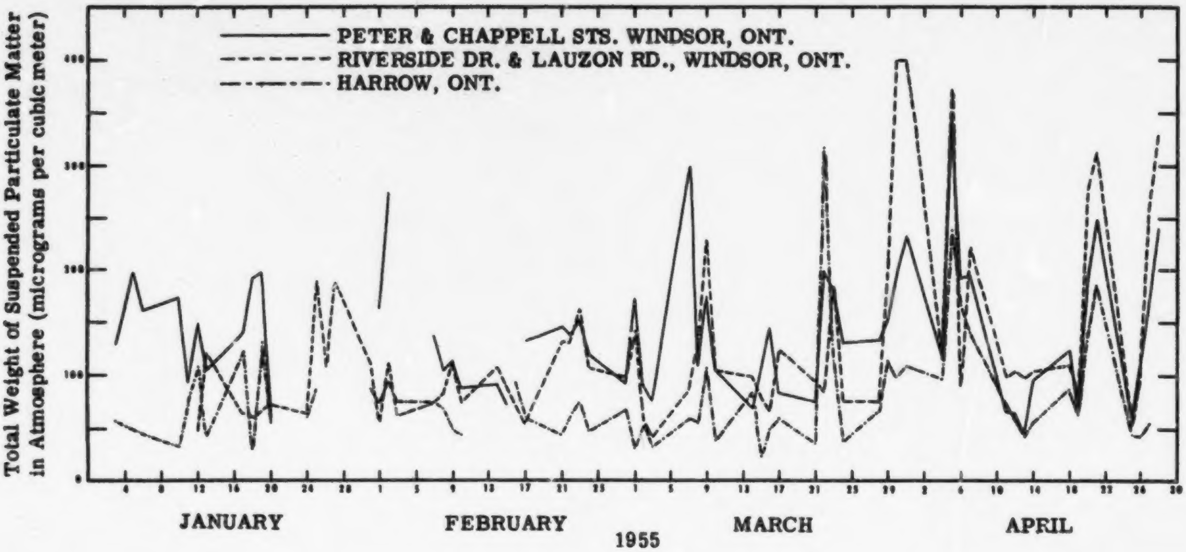


Figure VII-23. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, January through April, 1955

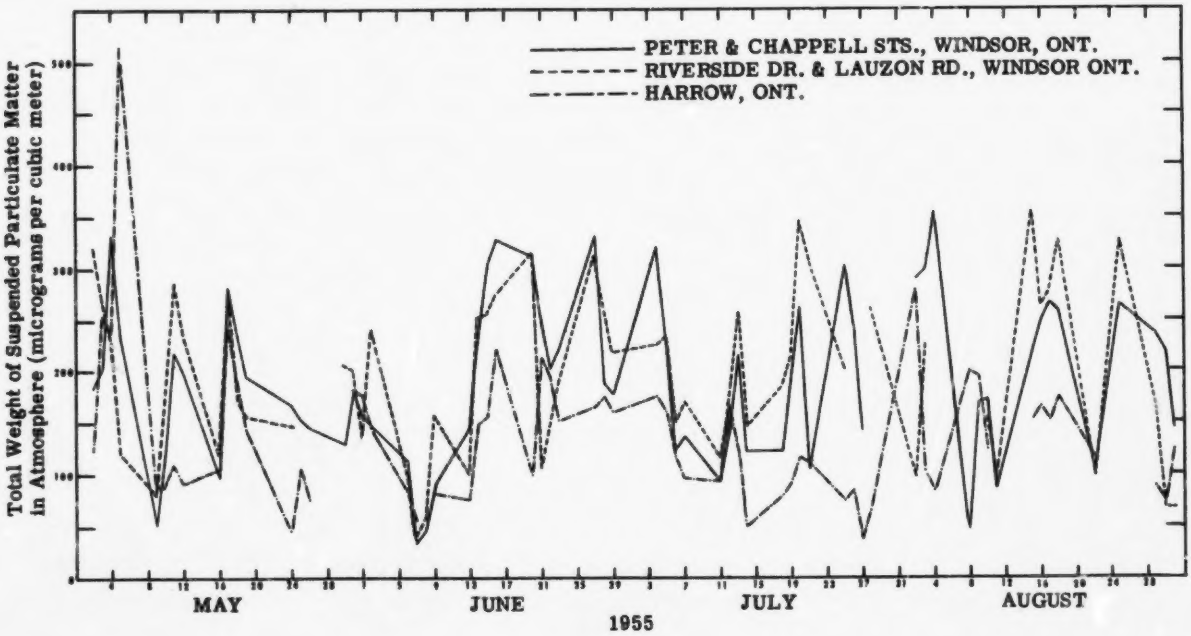


Figure VII-24. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Areas, May through August, 1955

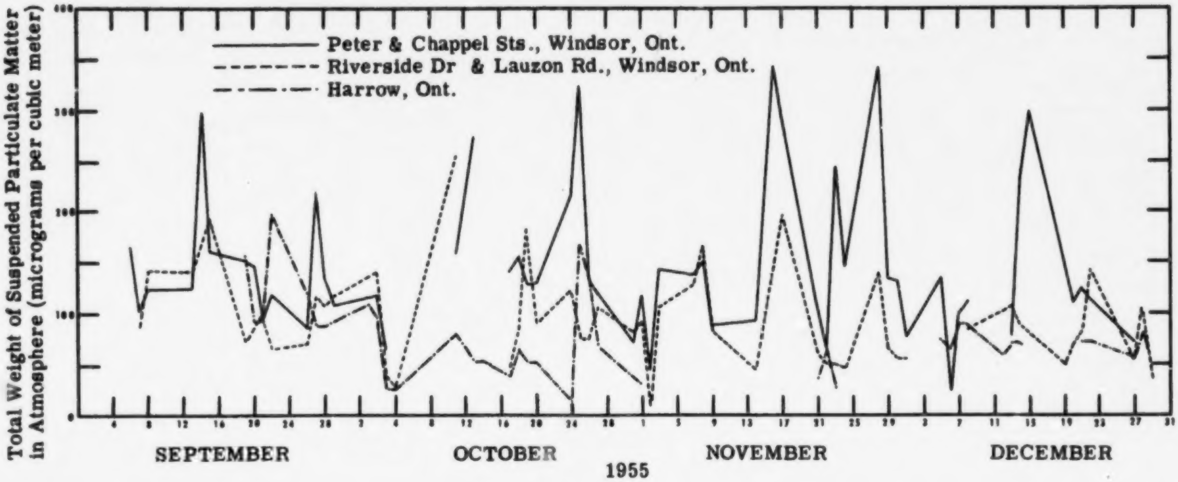


Figure VII-25. Daily Variation in Levels of Atmospheric Particulate Pollution in Canadian Health Study Area, September through December, 1955

minimum fluctuations at all three sampling stations show a substantial degree of correspondence, generally in phase, and it is evident that certain weather elements, common to these areas, exert a marked effect on the daily variation in pollution levels. Relatively high concentrations of pollution were associated with low wind speeds and abnormally higher than usual temperatures whereas a reduction in pollution generally followed each cold frontal passage. These weather influences on pollution levels are discussed in Chapter XI.

It is apparent from these graphs that on numerous occasions the particulate pollution levels in the Windsor low pollution area rose to about the same or to higher levels than the corresponding concentrations in the Windsor high pollution area, due to the additional contamination swept in from more distant sources under the influence of meteorological factors. On days of large inversions, relatively heavy particulate pollution levels extended over a large part of the study area and normal differences between so-called high and low pollution areas would tend to disappear.

The mean values for particulate loading of the atmosphere in the various Canadian and United States areas involved in the Health Study over the 2-1/2-year period, July 1953 through December 1955, are shown in Table VII-20. These means are in the expected order of concentration for the high versus low pollution areas of Windsor and Detroit. A separation of the data has been effected according to wind speeds of less than 10 miles per hour or greater, and also according to the principal wind directions. In general, the concentrations are higher at wind speeds of less than 10 miles per hour. In the Windsor area, the highest particulate loadings occurred in south, southwest and west winds. At the Detroit sampling stations the mean levels were greatest in east and south winds, with a considerable influence of west winds in the high pollution areas.

The above data, that have become available recently through information gained from operation of the United States National Sampling Network(10), on particulate loading of the atmosphere in the study area are substantially in agreement with values for cities of comparable size. Detroit particulate pollution levels are in the range established for cities of populations of two million and over, such as Chicago, New York, Philadelphia and Los Angeles. Although Windsor has a population of less than 200,000, its pollution levels are influenced considerably, on occasion, by activities in nearby Detroit. The Windsor particulate loading in the high pollution area shows a frequency distribution of 79.4 percent in the range of 51 to 250 micrograms per cubic meter of air, with only 3.3 percent of the

Table VII-20. Mean Particulate Loading in Micrograms per Cubic Meter of Air

Wind Direction	Windsor Station #1 (Peter & Chappell)		Riverside (Windsor) Station #2		Harrow, Ontario		Simcoe, Ontario	
	<10 mph	>10 mph	<10 mph	>10 mph	<10 mph	>10 mph	<10 mph	>10 mph
North	160	123	140	93	87	80	71	53
Northeast. . . .	163	116	155	66	119	91	148	115
East	159	148	122	143	88	81	115	120
Southeast	178	---	159	---	92	---	160	---
South.	209	128	198	86	99	44	117	29
Southwest. . . .	214	204	174	143	89	87	117	88
West	245	152	203	117	112	79	92	83
Northwest . . .	173	139	154	118	120	74	110	61

	Area 4		Area 20		Area 21		Area 24	
	<10 mph	>10 mph	<10 mph	>10 mph	<10 mph	>10 mph	<10 mph	>10 mph
North	183	179	208	175	123	96	127	102
Northeast. . . .	198	146	207	129	124	97	120	126
East	287	260	371	211	188	140	182	131
Southeast	244	---	257	---	190	---	178	---
South.	262	187	301	180	161	98	179	107
Southwest. . . .	229	167	207	209	117	101	129	116
West	250	160	255	238	129	92	139	102
Northwest . . .	211	155	217	140	139	102	148	101

Area 4	Highland Park - Hamtramck, 5 miles north of Detroit River.	High Pollution Areas
Area 20	North of River Rouge Area. Ford Rouge Plant Directly west. Zug Island is directly to southeast.	
Area 21	Residential, 5 miles due west of Area 4.	
Area 24	Residential, Oak Park, North of Area 21.	

observations in the range of 0-50 u/M^3, and about 4 percent in the highest range, between 401-550 u/M^3. In the Windsor low pollution area, 7.9 percent of the observations were in the range of 0-50 u/M^3, 77.8 percent in the class of 51-250 u/M^3, and only about 1.6 percent in the highest class range of 401-550 u/M^3 (Table VII-21).

In the most heavily polluted area in Detroit (area 20) as shown by the data for the period July through December 1953 in Table VII-22, the frequency of observations in the loading range of 51 to 250 u/M^3 amounted to 60.2 percent, with 12.8 percent in the class range of 401-550, and 3.9 percent consisting of observations running above this class up to a maximum of 1001-1050 u/M^3. One of the Detroit low pollution areas (area 21) was considerably cleaner than the other and was, in fact, less polluted than the Windsor low pollution area. Comparative frequency data for observations on the Canadian side of the study area during this period are shown in Table VII-23.

Trends in Particulate Loading

Although the study of air-borne particulate matter by means of the continuous operation of high volume samplers has not been continued long enough to establish a significant long-term trend, there is sufficient evidence to suggest that the reduction in the consumption of solid fuel and increase use of oil and natural gas since 1952,

Table VII-21. Frequency Distribution of Total Particulate Concentration in Windsor - August 1953 through December 1955

Concentration Micrograms per cubic meter	Windsor High Pollution Area	Windsor Low Pollution Area	Harrow
	Percent Occurrance		
0 - 50	3.3	7.9	26.3
51 - 100	18.1	31.3	40.2
101 - 150	30.0	25.0	16.9
151 - 200	19.6	12.7	11.9
201 - 250	11.7	8.8	3.7
251 - 300	7.7	6.7	0.5
301 - 350	4.2	3.7	0.3
351 - 400	1.5	2.6	---
401 - 450	1.8	0.7	---
451 - 500	1.1	0.7	---
501 - 550	1.1	0.2	0.3
551 - 600	---	---	---
No. of samples	441	431	403

Table VII-22. Frequency Distribution of Total Particulate Concentration in Detroit - July 1 through December 31, 1953

Micrograms per cubic meter	Sampling Station			
	4	20	21	24
	Percent Occurrence			
0 - 50	---	---	18.2	5.1
51 - 100	13.2	9.0	22.7	8.2
101 - 150	5.5	12.8	15.2	15.4
151 - 200	33.0	25.6	19.7	10.2
201 - 250	18.7	12.8	6.1	8.2
251 - 300	9.8	9.0	9.1	12.2
301 - 350	8.8	6.4	4.5	9.2
351 - 400	3.3	7.7	3.0	6.1
401 - 450	3.3	5.1	---	7.1
451 - 500	1.1	5.1	---	5.1
501 - 550	1.1	2.6	1.5	5.1
551 - 600	1.1	---	---	5.1
601 - 650	---	1.3	---	1.0
651 - 700	---	---	---	---
701 - 750	---	1.3	---	---
751 - 800	---	---	---	1.0
801 - 850	---	---	---	1.0
851 - 900	---	---	---	---
901 - 950	1.1	---	---	---
951 - 1000	---	---	---	---
1001 - 1500	---	1.3	---	---

and the abatement of smoke conditions on the Detroit River through the efforts of the voluntary control program have had an effect on the mean levels of particulate pollution. This trend is evident, to a certain extent, from an inspection of the graphs in Figures VII-18 to VII-25. It is also substantiated by the limited data presented in Table VII-24. However, several counteracting influences tend to complicate the picture.

It will be noted from Table VII-24 that the weight concentration of particulates tends to be higher during the period April through October (roughly corresponding to the nonheating season) than in the 5-month heating season of November through March. This trend is contrary to that shown for dustfall rates which increase, as expected, with the increased use of fuel for space heating. The explanation that air-borne particulate levels rise in the nonheating season, approximately coinciding with the navigation season, because of the influence of smoke from the heavy volume of vessel traffic on the Detroit River, and fall in the remaining five months, when vessel traffic is virtually at a standstill, is not adequate. The country towns of Harrow and Simcoe, Ontario, are similarly affected seasonally as regards particulate pollution levels but are beyond the influence of Detroit River vessel smoke. Other important factors that must not be overlooked in seeking the cause of such seasonal trends are the effects of wind speed, re-entrainment of dust and soil particles from the bare ground, precipitation and other weather influences.

It is known that the concentration of air-borne particulates varies inversely with the wind speed and wind speeds are lower in the summer than in the winter months in the Windsor-Detroit area. Furthermore, during the nonheating season, especially during agricultural activities in the surrounding rural district and the effects of heavy traffic on city streets when the ground is bare and dry, much more dust will be re-entrained and swept into the air than in the cold months when the ground is frozen and apt to be covered with ice and snow. Finally, there is more frequent precipitation in the cold months in this area, with resultant rapid decrease in particulate pollution levels. Increased fuel burning during the winter heating season results in increased emissions of particulates. The larger particles of relatively high settling velocity tend to fall out rapidly and contribute to the deposited dust, whereas the extremely fine particles of

Table VII-23. Frequency Distribution of Total Particulate Concentration in Windsor - August 11 through December 31, 1953

Concentration Micrograms per cubic meter	High Pollution Area Windsor, Ontario Ambassador Park	Low Pollution Area Windsor, Ontario Riverside Drive & Lauzon Road	Control Harrow, Ontario
	Percent Occurrence		
00 - 50	1.1	3.5	23.8
51 - 100	6.7	16.3	22.5
101 - 150	12.2	25.6	23.8
151 - 200	20.0	17.4	20.0
201 - 250	15.5	12.8	10.0
251 - 300	15.5	8.1	---
301 - 350	5.6	3.5	---
351 - 400	6.7	5.8	---
401 - 450	6.7	3.5	---
451 - 500	5.6	2.3	---
501 - 550	4.4	1.2	---
551 - 600	---	---	---
No. of Samples	90	86	80

Table VII-24. Seasonal Variation of Air-Borne Particulates - Mean Values in Micrograms Per Cubic Meter of Air

	Windsor		Harrow	Simcoe
	High Pollution	Low Pollution		
1953	247	177	101	---
August - October . . .	278	207	133	---
November - December	201	132	51	---
1954	161	138	71	---
April - October	187	154	82	---
November - March . .	125	116	55	46 (Nov. Dec.)
1955	170	141	98	98
April - October	180	170	119	132
November - March . .	157	100	69	54

smoke will remain suspended in the air but contribute only in a minor way to the mass concentration as determined by a high volume filter. All these complex factors enter into the anomalous seasonal trends exhibited by air-borne particulate levels as contrasted with dustfall and sulfur dioxide.

Size Distribution of Particulates and Examination by Electron Microscopy

Since retention in the lungs of dust suspended in inspired air varies markedly with particle size, the particle size distribution of air-borne particulates has received a great deal of attention. To determine the frequency distribution of size classes in the air-borne particulates characteristic of the Windsor-Detroit area, the methods previously described were used to examine 9 standard impinger samples and 12 thermal precipitator samples. For the impinger samples 87 percent of the total number of dust particles was found to be less than 2 microns in average diameter. Thermal precipitator samples contained 83.9 percent less than 2 u. The thermal precipitator demonstrated a greater collection efficiency than the standard impinger for dust below 0.50 u in diameter. Cumulative percentage curves for particulate sizes are shown in Figure VII-26. Analysis shows that the particulate sizes are log normally distributed, i.e. the log of the particle sizes plotted against frequency furnishes a typical normal frequency curve.

It is evident from a consideration of the nature of the deposit produced when polluted air is drawn through filter paper that the intensity of the stain or spot as measured by optical transmission or reflectance of light must bear some relation to the mass concentration of the particulate matter in the polluted air. This consideration is valid only if the sample of particulate matter is truly representative of the general pollution in the area, and if the sampling site is well removed from a source of fly ash or large dust particles so that the weight distribution curve is not inordinately skewed by the presence of particles greater in diameter than 10 u.

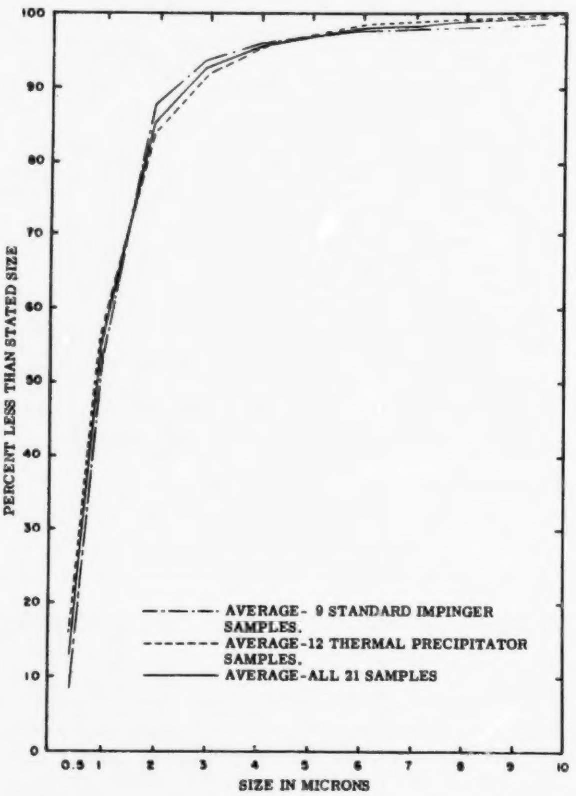


Figure VII-26. Particle Size Distribution of Atmospheric Dust

To provide a test of this hypothesis, the particle size distribution of the dust collected on filter paper by the Owens Smoke Filter in Windsor was determined, and an estimate was made of the mass concentration from the number count. Particles greater than 1.0 u in diameter were counted with the use of a stereoscopic microscope, which can resolve particles of this and greater diameters when they are imbedded in filter paper. Particles smaller than 1.0 were estimated by carefully dissecting individual fibers and counting the adhering particles with both high-power monocular and stereoscopic microscopes. A correction could thus be applied to the original count to include sizes down to approximately 0.5 u.

By weighing the group frequencies of particles classified by size in terms of the cube of the average diameter for each class and plotting in the same manner as for the size count analysis, the size mass distribution is obtained, and the mass concentration can be calculated(36).

Two test stains, estimated from the shade scale to be representative of mass concentrations of 65 micrograms per cubic meter and 120 micrograms per cubic meter respectively, were examined by the method described, and the mass concentrations were found to be 55 ug/M^3 and 144 ug/M^3.

These results constitute substantial evidence that measurements of optical properties of a deposit on paper are potentially useful in determining particulate concentrations in mass units. For the direct translation of optical density readings to mass concentrations of particulates, qualitative information on the nature of airborne particulates is probably necessary, and it may be that approximate values of one or more parameters not yet clearly defined would be required. Fundamentally, however, the work carried out in this study indicates a useful approach to the problem of measuring particulate pollution in this manner(38).

Electron microscopy was used to study the morphology of submicron dust particles (63). Samples were collected on millipore filters (Type AA, Lovell Chemical Company) during haze or smog periods in Windsor by aspirating air volumes in the range of 2 to 12 litres. The material, collected on the filter membranes without agglomeration and with high efficiency with respect to particles less than 1 u in diameter, was transferred by a suitable technique to electron microscope screens coated with formvar. The most widely distributed constituent was found to be carbon which was present in characteristic filaments. The filaments were all similar but varied in respect of the size of constituent particles which ranged from 0.5 to 0.20 u in diameter. Other particles recognizable by their distinctive appearance were diatoms and bacteria. Spherical particles closely resembled the metallic fume in the stack effluent of an electric steel furnace. Other crystalline particles 1 micron and greater in diameter were not identifiable. More detailed information on the identity of particulates was derived from X-ray diffraction studies.

The size and shape of some of these particles are illustrated in the photograph and electron photomicrographs in Figures VII-27 to VII-31, inclusive.

X-ray Diffraction Studies

The technique of identifying particulate matter by X-ray diffraction has been described. The unique feature of the method is that, unlike chemical, polarographic and spectrographic methods, it reveals the state of chemical combination of the crystalline constituents of particulates. Its limitation is that it gives no information about amorphous materials. However, the various means used to separate specimens from a sample of dust often afford indications of relative abundance of constituents both crystalline and amorphous. Compounds identified in dust collected on high volume pleated filters and

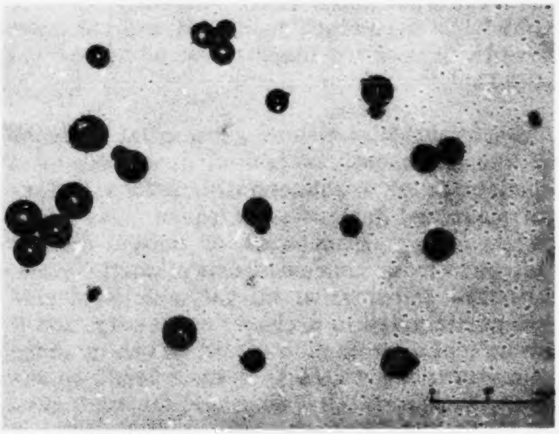


Figure VII-27. Photomicrograph of Particles of Magnetite

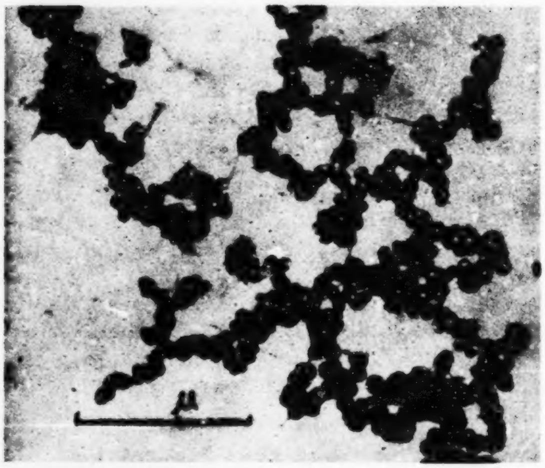


Figure VII-28. Electron Photomicrograph, Carbon Filaments of Average Particle Size.

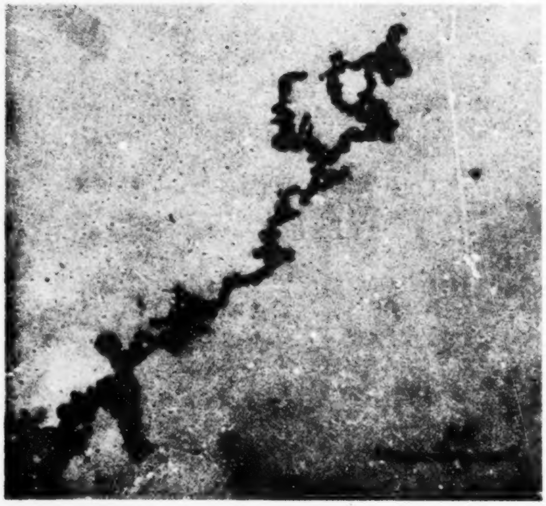


Figure VII-29. Electron Photomicrograph, Carbon Filaments of Small Particle Size.

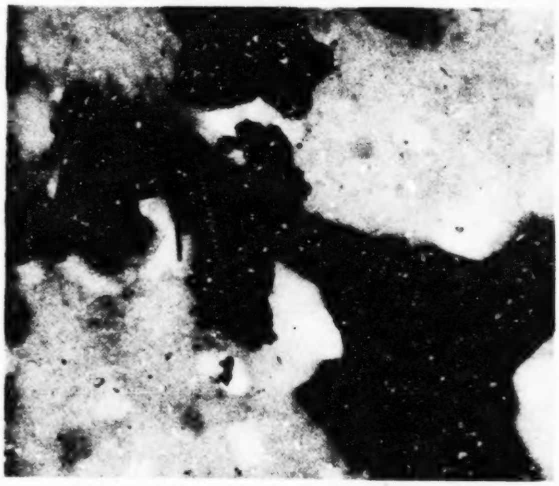


Figure VII-30. Electron Photomicrograph, Crystalline Particles.

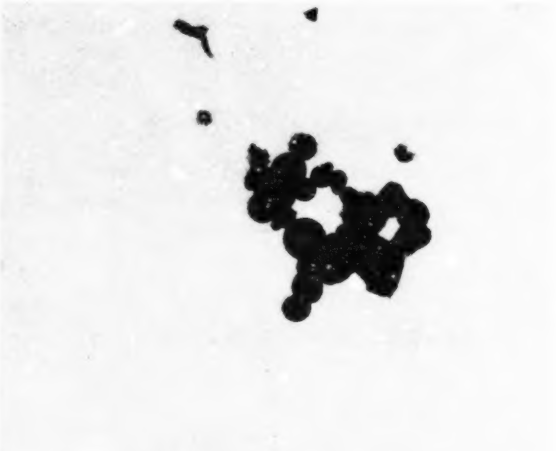


Figure VII-31. Electron Photomicrograph, Metallic Fume.

on glass slides in cascade impactors are listed in Table VII-25. In Figures VII-32 to VII-41, inclusive, the top half of each photomicrograph shows the X-ray diffraction pattern of the specimen sampled from dust as explained in Table VII-25; the bottom half shows the diffraction pattern of the standard reference sample.

The X-ray diffraction studies showed a fair measure of agreement with the quantitative spectrographic analyses. Concentrations of silicon, calcium, aluminum and iron by spectrographic analysis were respectively 6.21, 3.26, 2.75 and 2.49 micrograms per cubic meter. Qualitative estimates of abundances from X-ray diffraction data were in agreement. The remaining elements identified spectrographically were present in concentrations of less than 1 m4/M^3. Compounds containing about half of them were identified by X-ray diffraction.

The Benzene - Soluble Fraction of Air-borne Particulates

Some information about the quantity and quality of the carbonaceous material in airborne particles was furnished by X-ray diffraction and electron microscopy. More information would have been available had it been possible to remove the dust quantitatively from the pleated filters of high volume samplers, and comparison by percentage weight of the combustible fraction of deposited particulates and air-borne particulates would have been useful. Manipulative difficulties made this out of the question, however, and further characterization of the carbonaceous fraction of particulates was sought by the method of solvent extraction.

Solvent extraction was facilitated by the initiation in November 1955 of the use of flash-fired fiber glass filters instead of pleated paper filters in high volume samplers. The daily high volume samples from three stations were extracted with benzol in Soxhlet apparatus. Monthly averages of the three stations for ten months are shown in Table VII-26.

These results indicate that the association of carbonaceous material with air-borne particulates is a phenomenon of some complexity. The percent by weight of chemically combined carbon as represented by the benzene extractable is small compared with the percent by weight of combustible material in dustfall samples, and, while the weight loss of dustfall samples on ignition (around 30 percent) cannot be attributed entirely to the combustion of carbon or carbon compounds, and it cannot be assumed that dustfall and high volume filter samples contain the same percentage by weight of combustibles, it seems safe to assume that the ratio of chemically combined to total carbon is very small. How the ratio varies and what bearing it may have on methods, for example, of separating carcinogenic materials from particulates are matters requiring consideration.

Table VII-25. Identification of Constituents of Air-Borne Particulates By X-Ray Diffraction

Means of Sampling	Chemical Constitution	Remarks
Random samples from different filters. . .	$Si\ 0_2$ $Ca\ C0_3$	Present as the main diffracting constituents on all filters examined.
Manual sorting with low power microscope	$Ca\ C0_3$ $Si\ 0_2$ Aluminum	L - quartz was found to be the most common crystalline constituent
Extraction of gross sample with distilled water and recrystallization.	$CaS0_4\ 2H_20$ $NH_4\ C1$	Gypsum
	$Fe_3\ 0_4$	Highly magnetic, bluish-black, string spheres magnetite, 5-30 u in diameter
Magnetic separation from gross samples .	$Fe_2\ 0_3$	Less strongly magnetic, orange particles, in loose aggregates, hematite
	$Sn\ 0_4$	Dull black plates proved to be a mixture of hematite, magnetite and stannic oxide
Sedimentation in gelatin solution	C $Ni\ F_4$	Graphite
		Black, coal-like particles, widely distributed in the samples were amorphous, and unidentifiable by the method
	Metallic -	Yellow brass
Deposits on slides of cascade impactors . .	Metallic -	Solder
	$Cd\ C0_3$	Transparent, blue tinged plates

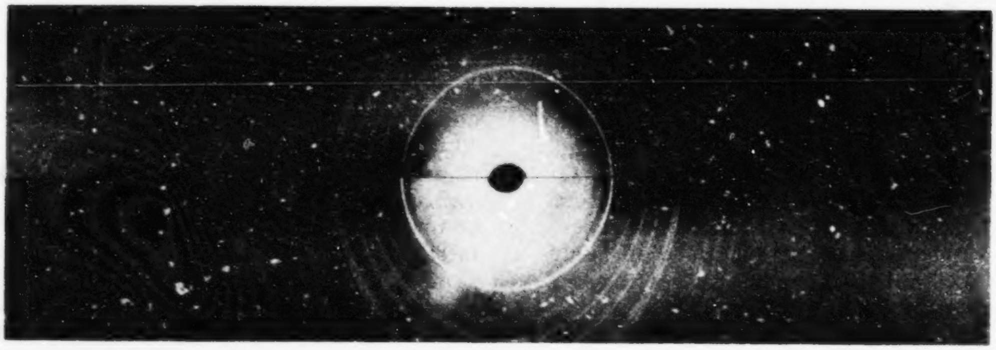


Figure VII-32. Diffraction Patterns of White Particles from Dust and $CaC0_3$. Upper Section - White particles from dust. Lower Section - Pure $CaC0_3$.

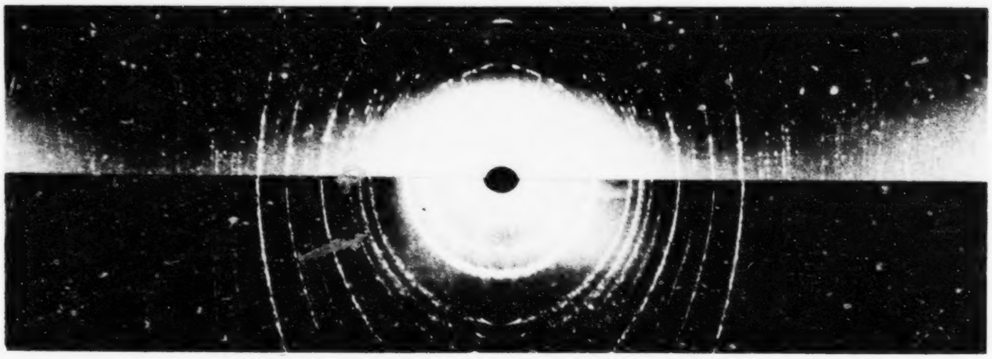


Figure VII-33. Diffraction Patterns of Transparent Particles from Dust and SiO_2. Upper Section - Transparent particles from dust. Lower Section - SiO_2.

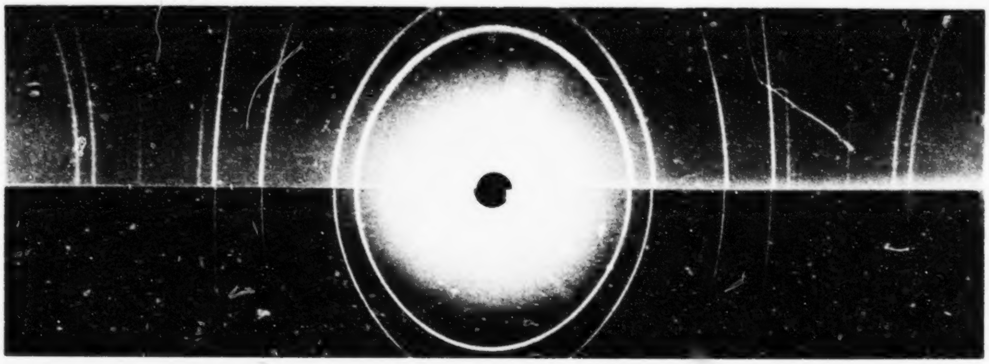


Figure VII-34. Diffraction Patterns of Metallic Particles from Dust and Aluminum. Upper Section - Shiny metallic particles from dust. Lower Section - Pure aluminum.

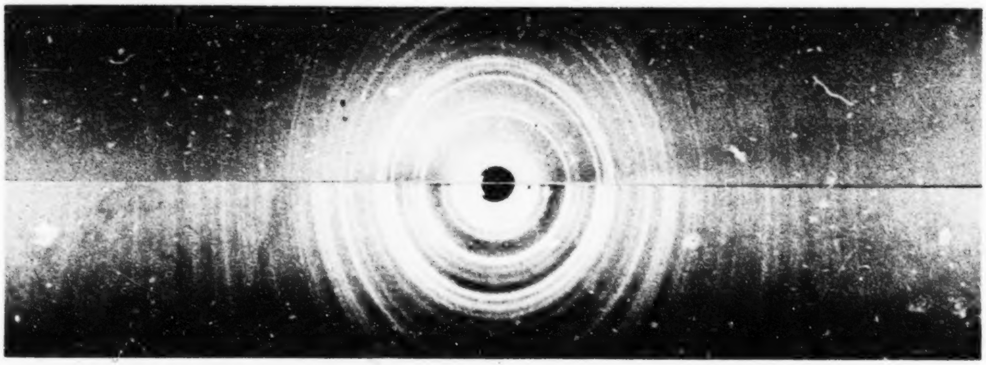


Figure VII-35. Diffraction Patterns of Particles Recrystallized from Water Extract of Dust and $CaSO_4.2H_2O$. Upper Section - Particles recrystallized from water extraction of dust. Lower Section - $CaSO_4.2H_2O$.

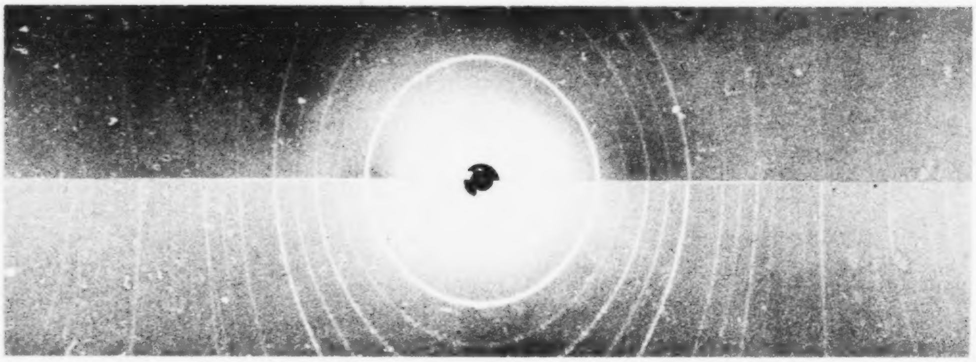


Figure VII-36. Diffraction Patterns of Particles Recrystallized from Water Extract of Dust and NH_4Cl. Upper Section - Particles recrystallized from water extraction of dust. Lower Section - Pure NH_4Cl.

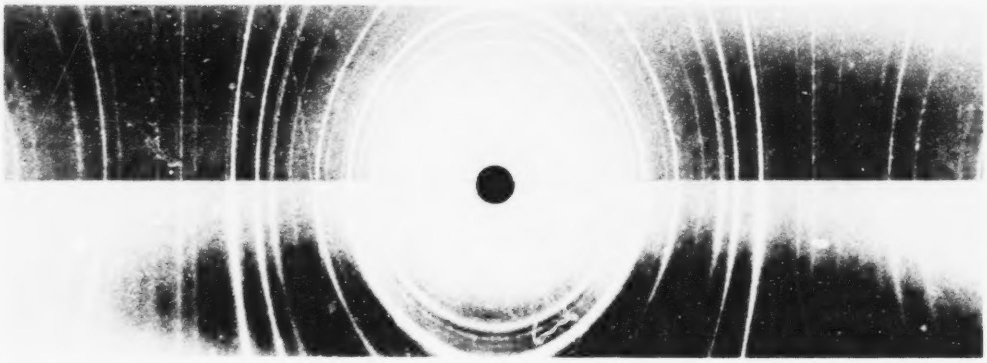


Figure VII-37. Diffraction Patterns of Strongly Magnetic Particles from Dust and Fe_3O_4. Upper Section - Strongly magnetic particles from dust. Lower Section - Pure Fe_3O_4.

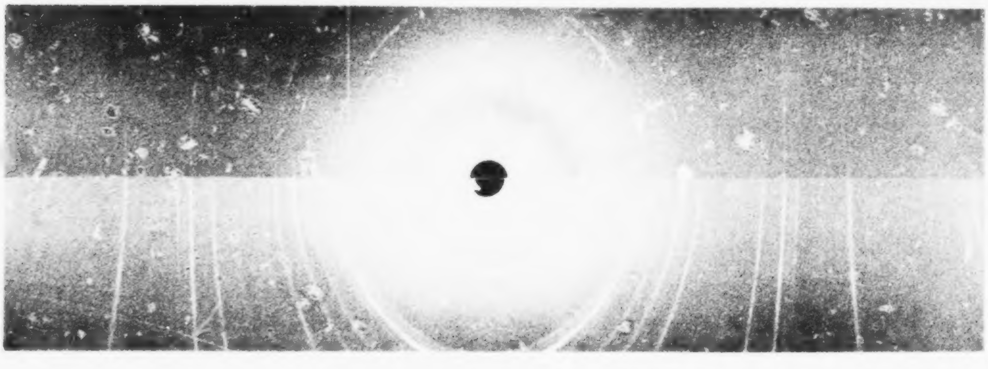


Figure VII-38. Diffraction Patterns of Black Flakes from Dust and Graphite. Upper Section - Shiny black flakes from dust. Lower Section - Graphite.

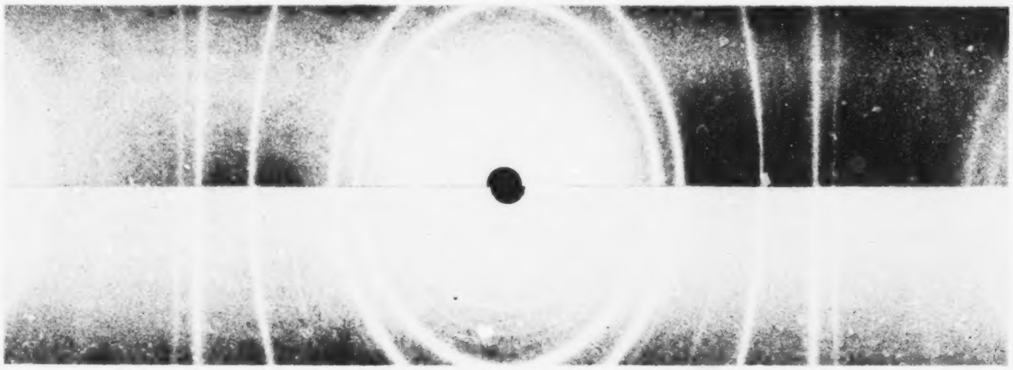


Figure VII-39. Diffraction Patterns of Metallic Particles from Dust and Brass. Upper Section - Golden metallic particles from dust. Lower Section - Brass.

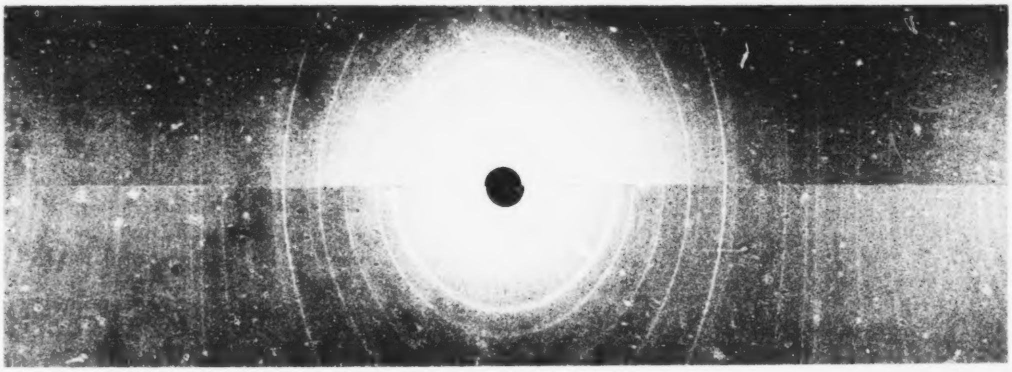


Figure VII-40. Diffraction Patterns of Metallic Particles from Dust and Solder. Upper Section - Silvery metallic particles from dust. Lower Section - Solder made from equal portions of lead and tin.

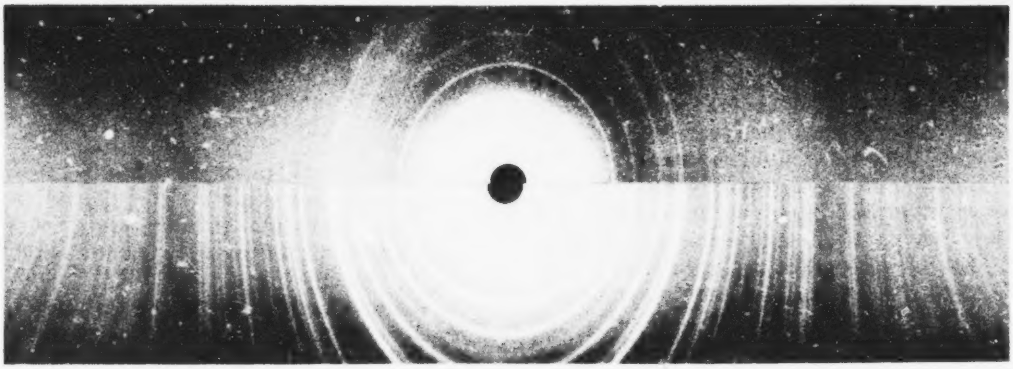


Figure VII-41. Diffraction Patterns of Transparent Plates from Dust and $CdCO_3$. Upper Section - Transparent plates from dust. Lower Section - Pure $CdCO_3$.

Table VII-26. High Volume Filter Sample Material Extractable with Benzene

Average of three stations - mean values for each month

Month	Grams of benzene extractables per 100 grams of particulates	Concentration of extractables in micrograms per cu. meter of air
Dec., 1955	5.4	5.4
Jan., 1956	8.6	7.8
Feb., 1956	8.9	7.3
Mar., 1956	7.3	4.9
April 1956	5.8	6.2
May, 1956	5.5	4.5
June, 1956	3.5	5.2
July, 1956	4.1	4.0
Aug., 1956	3.2	3.7
Sep., 1956	3.5	4.0

Examination of the data shows a rough parallelism between variations of percentage extractable and mass concentration. Ten months is much too short a time to establish the reality of an indicated seasonal trend, but the results shown in Table VII-26 indicate corresponding peak values for the winter months for the two methods of presenting the concentrations. A possible explanation is that during months of increased domestic heating when the efficiency of fuel combustion is low, the background particulate loading of the atmosphere is increased by quantities of material containing higher percentages of benzene extractable matter.

Detailed comparison of data for various localities on the benzene extractable fraction of particulates is not possible. Roughly relevant information is given in "A Comparison of Particulate Loadings in the Atmosphere of Certain American Cities" (10). Here, the average for seven cities of population between 500,000 and 2,000,000 for acetone soluble extractives is about 22 micrograms per cubic meter of air. The difference between this value and the 5.3 micrograms per cubic meter average for Table VII-26 cannot be accounted for by the fact that acetone extracts inorganic as well as organic materials from particles.

Polynuclear Aromatic Hydrocarbons in Particulates

The presence in urban atmospheres of carcinogenic aromatic hydrocarbons and the increasing incidence of lung cancer were first associated in 1947(40) as having a possible cause and effect relationship. Since then interest in the subject has expanded rapidly. At present the most promising method for separating the aromatic fraction from organic solvent extracts of particulate matter is a combination of paper chromatography and column chromatography. Paper chromatography is superior to the latter in its ability to resolve very small quantities of closely similar polynuclear aromatics. Column chromatography together with ultraviolet absorption spectroscopy offer the best hope for quantitative estimation of concentrations of hydrocarbons in air.

Most of the particulate samples in this study consisted of the total particulates removed from approximately 2500 cubic meters of air during a 20-hour period by a high volume sampler adapted to use flat sheets of flash-fired, fiber glass filters. Larger samples comprised materials collected during a two-month period on fiber glass filters at the air intake of an air-conditioning unit in a high pollution area.

Samples of approximately 2 grams were extracted with chloroform and the extracts were transferred to 20 c.c. volumes of cyclohexane for elution on 20 x 1.1 cm. aluminum oxide columns. On a developed column four bands could be distinguished in ultraviolet light. These consisted of:

1. A colorless band at the bottom of the column, with a very faint blue fluorescence

2. A colorless band with strong blue-violet fluorescence

3. A yellow band with green fluorescence

4. A dark brown band at the top of the column.

Band 1 would be expected to contain paraffins, naphthenes and olefins. The ultraviolet absorption spectra indicated the presence also of some conjugated diolefins or benzene derivatives.

Band 2 comprised a number of polynuclear condensed-ring aromatic hydrocarbons, of which pyrene, fluoranthene, benz(a)anthracene, chrysene and benzo(e)pyrene were identified. The presence of benzo(a)pyrene was indicated, but the separation was not sharp enough to permit unambiguous identification.

Band 3 showed extremely strong ultraviolet absorption throughout the spectral range of 2200 to 4000 A for all fractions from the band. The band probably contained higher members of the aromatic series consisting of 5 and 6 condensed rings, but no clear-cut identifications were made.

Band 4 would be expected to contain any nitrogen or oxygen compounds together with acids, phenols and bases.

The results described are somewhat less than definitive, but the fact that typical members of the class of organic materials containing the known and suspected carcinogens were positively identified and shown to be present in particulates from the area is in itself a significant contribution. The presumption is that other compounds of special interest from an environmental health standpoint are also present and the desirability of further work is indicated.

A sample of dust collected from the intake of the air-conditioning unit was extracted with carbon tetrachloride to give a sample sufficiently concentrated for infrared analysis. The presence of aliphatic and aromatic C-H bands was indicated by strong absorption bands at 3.4 and 3.5 microns wavelength. The band at 5.8 microns was considered due to aldehyde, ketone or ester and that at 5.85 microns to carboxylic acid. The presence of the acid was confirmed by saponifying the extract with aluminum isopropoxide and obtaining the characteristic soap band at 6.3 microns. The spectrum of the extract was similar to those obtained for Philadelphia, Houston and Detroit(11) except for the presence in the Windsor chart of a strong band at 10.3 microns. In the analysis of gasoline a band in this region has been assigned to olefins with an internal double band(35), but in the present instance no change was observed after treatment of the extract with iodine monochloride.

Pollution Levels Measured by Automatic Smoke Samplers

Automatic smoke samplers, of the A.I.S.I. type, were operated continuously for various lengths of time at selected stations in Windsor and Detroit. The results for one such period extending from February 3, 1954, to March 12, 1954, and comprising data from nine stations, five stations in Windsor, three stations in Detroit, and one at the town of Harrow, are summarized in Table VII-27.

With the exception of the sampling station at the country town of Harrow, Ontario, about 22 miles south of the Detroit River, the sampling sites were located along a strip of territory close to the banks of the Detroit River on both sides of the International Boundary. It is noted that, in terms of the soiling index or Coh's per 1000 linear ft. of air, the mean pollution levels at both Windsor and Detroit stations for sites located at opposite points of the river are remarkably consistent. At the most heavily polluted stations, the mean levels are about 4 times the level observed at Harrow, Ontario. At the less heavily polluted sites, these levels are about 2 to 3 times greater than at Harrow.

Table VII-27. Soiling Indices in Coh's Per 1000 Linear Feet of Air
February 3, through March 12, 1954

Station Number	Location	Period of Operation (days)	Mean	Median	Maximum	Minimum
102	Wyandotte, Detroit	7	1.2	1.1	3.3	0.2
103	LaSalle, Windsor	15	1.3	1.3	11.6	0.1
105	Peter and Chappell, Windsor . . .	19	1.5	1.2	7.0	0.7
106	Riverside Park, Detroit.	19	2.2	2.2	13.5	0.7
107	Caron and Sandwich, Windsor. . .	7	2.2	2.4	6.1	0.3
109	D.M. Ferry Bldg., Windsor . . .	28	2.3	2.1	7.7	0.7
112	U.S.P.H.S. Hosp., Detroit. . . .	8	1.9	1.5	6.7	0.3
113	Riverside, Windsor	36	1.6	1.5	8.7	0.3
115	Harrow, Ontario	35	0.6	0.5	3.7	0.0

A two-year run at the Herman Kiefer Hospital, Detroit, is summarized in Table VII-28. Results here are given in terms of average optical densities by reflectance for four-week periods and three months periods, and are comparable among themselves for the study of seasonal trends.

Seasonal trends, in harmony with the Detroit data, are also manifested in the results of a study of more than two years from July 27, 1955 to November 30, 1957 at the Peter and Chappell sampling station Windsor. A seasonal frequency distribution of the soiling indices over this period in terms of Coh values per 1000 linear feet of air is shown in Table VII-29.

The Coh values are considered to be roughly indicative of the fine air-borne particulates representing smoke and haze particles. In general, such smoke particles are less than 5 microns in diameter and the majority is of submicron size. The heaviest pollution of this type, in Windsor, occurs during the winter and the lowest concentrations prevail during the summer months. Smoke conditions in the spring are worse than in the fall period.

The well defined peak for the winter season which is evident in Tables VII-28 and VII-29, most probably reflects the increased emission of smoke from domestic heating units. It is out of phase with the seasonal peak shown in high volume filter data, but agrees well with the seasonal location of peaks for dustfall and sulfur dioxide data. Tabulations of high volume filter results show the pollution peak occurring in the spring and summer seasons. Possibly the real explanation for the winter peak in soiling indices is that the albedo of air-borne particulates

Table VII-28. Optical Densities of Particulate Stains In Detroit

Averages for four week periods 1953, 1954

Period		a. m. Averages		p. m. Averages	
		1953	1954	1953	1954
January	1	-	.17	-	.10
	2	.17	.17	.08	.05
	3	.13	.13	.07	.05
April	4	.09	.09	.04	.04
	5	.10	.07	.05	.03
	6	.06	.06	.04	.03
July	7	.05	.05	.02	.02
	8	.05	.05	.03	.03
	9	.06	.02	.02	.02
October	10	.15	.09	.03	.04
	11	.15	.09	.05	.03
	12	.15	.18	.05	.05
December	13	.14	-	.08	-
Seasonal Averages (Three Month Periods)					
Winter	1*	.14	.16	.08	.07
Spring	2	.10	.09	.08	.04
Summer	3	.05	.05	.02	.03
Fall	4	.14	.06	.04	.05

*Season 1: Winter, Three months, December, January, February.

Table VII-29. Frequency Distribution of Smoke and Haze Concentrations at Peter and Chappell Streets, Windsor

Frequency of Coh Values per 1000 Linear Feet of Air in Percent of Observations at Indicated Class Range

Class Range Coh's per 1000 linear feet	Winter Dec.-Feb. Percent	Spring Mar.-May Percent	Summer June-Aug. Percent	Fall Sept.-Nov. Percent
0.0 - 0.4	2.9	15.9	38.6	18.9
0.5 - 0.9	16.4	36.0	36.3	39.0
1.0 - 1.4	23.4	11.4	7.3	9.4
1.5 - 1.9	36.7	27.7	14.8	26.9
2.0 and greater.	20.6	9.0	3.1	5.8
Total	100.0	100.0	100.0	100.0

varies seasonally. It is probable that the particulates characteristic of the spring and summer seasons contain a larger proportion, than in the winter of heavier, light-colored, or transparent particles, consequently the optical density readings of filtered deposits, the soiling indices, would tend to be low, whereas the weight concentrations from high volume filters would tend to increase, especially in summer.

It is apparent that the seasonal trends in soiling index correspond roughly to the increased use of solid and other fuels during the heating season in the study area. This influence overshadows, by far, any ameliorating effect on smoke conditions that might be expected from the cessation of Great Lakes traffic on the Detroit River from December to April. Consumption of solid fuel by industry and the public in this area from data in Chapter VI on land-based sources is approximately 60 times greater than the fuel consumed by vessels in transit on the Detroit River. Even if due allowance is made for the fact that the smoke from vessels is distributed within a relatively narrow strip of territory, whereas that from land sources is of area-wide distribution, the vessel-smoke effect is still of minor character in relation to the trends discussed here. A single large thermal power station in this area will burn more coal than that consumed by all vessels engaged in Detroit River traffic.

Space does not permit a detailed comparison of pollution levels in high and low pollution areas on the basis of soiling indices, as was done with dustfall and high volume filter data. A subjective evaluation, however, leads to the conclusion that the ratio of high to low pollution as estimated from soiling indices is about the same as the ratios estimated from dustfall and high volume filter data.

The Coh unit or soiling index for the evaluation of urban pollution has been adopted in an increasing number of cities. Coh values for Minneapolis, Louisville, Pittsburgh and Berkeley, California are available, and some of the data are shown in Table VII-30, together with average means from Detroit-Windsor, subject to the qualification that they may not be strictly comparable for reasons discussed only briefly below, but in greater detail elsewhere(38).

The basic difficulty in the cross comparison of data from one area to another is the incorrect assumption that the optical density of particles deposited on filter paper involves a linear relation to the volume of air filtered, with constant area of deposit. The particulates suspended in an urban atmosphere are not of uniform size, and the composition of the material may be expected to vary in a given locality or from one place to another. Any marked change in meteorological conditions will influence the albedo of the deposit.

Table VII-30. Coh Values for Various Localities

Locality	Average Coh's per 1000 linear feet of air	
Minneapolis	1.0	(77)
Louisville	2.6	(77)
Pittsburgh	2.0	(77)
Akron	0.5	(77)
Detroit, Urban . . .	1.8	
Windsor, Urban. . .	1.8	
Harrow, Ontario . .	0.6	
Berkeley, California	0.7	(70)

NATURAL RADIOACTIVITY

In the course of monitoring natural radioactivity at Brookhaven National Laboratory, it was observed(43) that alpha particle counts were high during periods of calm air and temperature inversion and were almost directly proportional to the intensity of the inversion. It was suggested by Cowan(15) that the intensity of natural radiation might serve as an index of vertical stability, hence as an index of the diffusion capacity of the atmosphere.

In 1952, the Industrial Hygiene Division of the Detroit Department of Health instituted a program of measuring natural radioactivity to evaluate the suggestion. In the same year, a preliminary report on the study was published (66) and later, 1955, a detailed analysis of three years' data was presented by Baynton in Progress Report No. 9(4).

The instrumentation used in Detroit was a compromise as compared with the very elaborate facilities available at Brookhaven. The particulates contained in 15 cubic feet of air were collected in the course of 30 minutes on 1-inch discs of filter paper, and the discs were then placed in the chamber of a quartz fiber electrometer. Electrometer readings were taken at intervals of 5, 10, 15, 30 and 60 minutes. Interpretation of electrometer readings in absolute radiation units was not attempted. Instead, the deflection in scale divisions in 30 minutes, less the background drift of the instrument, was determined and the result multiplied by two was recorded as radioactivity in scale divisions per hour. The method was said to measure essentially the intensity of radon gas activity arising from the radioactive decay of rock, soil, etc. at the sampling site. The particulate decay products of radon, which were retained on the filter disc were relatively short-lived; the half life was estimated to be about 40 minutes.

The weather factors which influence the observed radioactivity in air have been studied in some detail in Germany(33). The relationship is complex; some weather elements affect rate of emission of radioactive emanations, others affect rate of diffusion and some affect both rates. Factors which inhibit the rate of emission are precipitation, increase in barometric pressure, and frost. The rate is increased by solar radiation and rise in temperature, and by wind which accelerates the emanation from ground capillaries. Winds which increase the rate emanation increase also the rate of diffusion. Inversions are associated with high levels of activity, as noted previously. Seasonal trends of radioactivity are toward maxima in the fall and minima in the spring.

In the detailed analysis of three years' data, natural radioactivity was correlated with weight concentrations of suspended particulate pollution. Radioactivity readings, excluding observations during periods of rain, were selected from the data for each of the four seasons and correlated with associated observations on weight concentration of particulate pollution. Separate correlations for the seasons were made to ensure approximate homogeneity of samples. The results of the correlations are shown in Table VII-31.

Correlation was entirely absent in the spring and most marked in summer. Further probing showed the undesirability of including data on radioactivity for days when the ground was wet.

Following the preliminary tests, which limited the data which might be expected to prove useful to morning periods of dry days in June, July, and August of 1954, the detailed analysis consisted of the development of multiple regressions between natural radioactivity and various weather factors. The factors chosen were the thermal factor, defined as the sum of 24-hour temperature change and the surface temperature anomaly, wind speed, barometric pressure, and difference between dry and wet bulb temperature at a fixed time of day.

It was found that the several partial regression coefficients expressed the following relationships:

1. Natural radioactivity increased as temperature rose and stability increased.

2. It decreased as the pressure increased.

3. It decreased as the wind speed increased.

4. It increased as the relative humidity decreased.

Variations were accounted for mainly by the first, to a lesser and nearly equal degree by the second and third, and to a much smaller degree by the fourth factor mentioned above. As each regression equation was developed, the standard

Table VII-31. Comparison of the Correlation Coefficients Between Particulate Pollution at Area Four in Detroit and Natural Radioactivity at the Herman Kiefer Hospital

Season	Number of Days in Sample	Observed Values			Significant Values	
		a.m.	p.m.	mean	5%	1%
Spring	32	0.113	0.091	0.127	0.347	----
Summer	35	0.593	0.023	0.528	0.335	0.430
Fall	35	0.413	0.425	0.460	0.335	0.430
Winter	40	0.451	0.029	0.284	0.312	0.403

error of estimate was computed and compared with the standard deviation of observed radioactivity. It was concluded that variation of natural radioactivity was not too successfully accounted for by consideration of the particulate set of independent variables chosen.

RESULTS OF GASEOUS SAMPLING

SULFUR DIOXIDE

This gas is one of the principal contaminants in the study area and is derived mainly from the combustion of the sulfur in fuels. The annual fuel usage consists of about 13 million tons of coal, 4.3 million tons of fuel oils and 3.8 million tons of natural gas, the latter being of negligible significance as a source of sulfur dioxide. On a conservative basis, it has been estimated in Chapter VI that about 1100 tons of sulfur dioxide are discharged daily to the atmosphere in the study area, and of this total about 655 tons represent the emissions from industry and commerce while activities of the general public account for the balance.

A considerable effort has, therefore, been made to study the daily fluctuations and seasonal trends in sulfur dioxide pollution as well as the area-wide distribution of this contaminant in the Windsor - Detroit area. Measurements were also made in small communities remote from the Detroit River. The monthly mean and maximum concentrations at all sampling stations on the Canadian side of the study area over the period September 1950 to December 1955 are given in Table VII-32. In the Windsor high pollution areas, the highest monthly mean was 0.20 p.p.m. and the highest maximum 1/2 - hourly concentration reached 1.45 p.p.m. In the Windsor low pollution areas, the highest monthly mean was 0.073 p.p.m. with a peak of 0.50 at the Walker & Mohawk Station, whereas at Riverside the corresponding values were 0.037 and 0.54 p.p.m. At McGregor, Ontario, a small rural community about 15 miles south of the Detroit River, the highest monthly mean was only 0.027, but the peak concentration attained a value of 0.876 p.p.m. Farther distant from the Detroit River, at Harrow, Ontario, the highest monthly mean was only 0.022, and a peak value of 0.135 p.p.m. was attained.

Over a seven-month period of observations at Simcoe, Ontario, the data showed a maximum monthly mean of 0.002 and a peak of 0.055 p.p.m.

With respect to comparative levels of sulfur dioxide pollution, the monthly mean concentrations in the high pollution areas of Windsor, within the industrial-commercial zones, were about four-to six-fold greater than the values found within the residential suburban or low pollution areas. The data in Table VII-32 also illustrate the extent of dilution and dispersion of sulfur dioxide with distance from the Detroit River. For example, there are no significant sources of this gas at the McGregor, Ontario, station which is about 15 miles south of the river. Therefore, any concentrations registered at this station would represent exotic pollution swept in from the heavily industrialized Detroit River region. Monthly mean concentrations over the period from September 1950 to January 1953 at McGregor were about 10 to 30 times lower than corresponding means found at the most polluted Windsor station. However, on a number of occasions, fumigations with relatively high concentrations of gas were recorded at McGregor, as shown by the marked variation in the range of monthly maximum concentrations, from 0.031 to 0.876 p.p.m., over a three-year period.

The detailed frequency distributions of sulfur dioxide concentrations at all sampling stations in the study area have been presented to the International Joint Commission in annual progress reports(105). Some of these data, in a more condensed form, are presented in Tables VII-33 and VII-34. In the Windsor high pollution area, the greatest frequency of concentrations above 200 parts per billion occurred in December 1953, i.e., 9.2 percent of the time. Such concentrations were present for 2.8 percent of the time in the low pollution area over the same period. Similar occurrences of relatively high concentrations were recorded for 4.8 percent of the time in February 1954 in the high pollution area, and for 2.1 percent duration in the low pollution area. In April of 1955, about 4.0 percent of the concentrations in the Windsor high pollution area exceeded 200 parts per billion. The highest frequency of gas concentrations in this range in the low pollution area during 1955 was about 0.60 percent. It is apparent that sulfur dioxide conditions in the fall and early winter months of 1953-1954 were more severe than in subsequent seasons of this study period. This is illustrated clearly by the graph in Figure VII-42.

At Harrow, Ontario, during the test period from November 1953 to December 1955, most

Table VII-32. Sulfur Dioxide Concentration in the Greater Windsor Area

Stations in High Pollution Area	Peter & Chappell Caron & Sandwich McDougall & Sandwich
Stations in Low Pollution Area	Riverside Walker Road & Mohawk LaSalle, Ontario
Stations in Control Area	McGregor, Ontario Harrow, Ontario Simcoe, Ontario

Year & Month	Peter and Chappell		Caron and Sandwich		Walker Road and Mohawk		McGregor, Ontario	
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
	Concentrations in parts per billion							
1950								
Sept.	26	96	74	308	33	294	10	155
Oct.	23	173	71	264	28	185	12	142
Nov.	35	149	63	326	22	214	11	307
Dec.	45	183	91	557	59	317	27	252
1951								
Jan.	20	108	73	250	3	62	1	44
Feb.	34	221	88	285	8	185	3	59
Mar.	38	225	76	207	3	95	3	31
April	49	288	107	413	8	189	1	39
May	38	335	122	363	7	230	3	69
June	14	83	47	228	6	79	4	66
July	62	496	70	387	6	85	1	80
Aug.	33	407	88	234	8	98	4	102
Sept.	37	259	93	275	8	130	3	92
Oct.	47	193	119	465	21	234	3	94
Nov.	48	347	104	421	19	146	5	105
Dec.	55	229	149	445	40	294	10	96
1952								
Jan.	43	154	121	510	25	173	10	136
Feb.	81	376	143	535	<10	<10	<10	35
Mar.	91	680	82	408	<10	<10	<10	32
Apr.	50	621	90	469	<10	42	<10	251
May	41	578	89	592	--	--	<10	126
June	98	1120	70	283	--	--	<10	73
July	116	1370	116	410	38	152	5	119
Aug.	84	505	120	378	19	413	5	218
Sept.	69	1454	109	378	18	504	15	876
Oct.	89	692	134	389	46	358	7	135
Nov.	54	500	102	355	73	410	6	105
Dec.	50	448	200	546	--	---	10	115

Table VII-32 (Cont'd.)

Year & Month	Peter & Chappell		Riverside		Caron & Sandwich		LaSalle, Ontario		McGregor, Ontario	
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum
1953										
Jan.	58	220	--	---	127	400	5	115	8	85
Feb.	81	420	--	---	80	315	10	70	<10	110
Mar.	70	325	--	---	96	460	<10	100	20	95
April	59	215	--	---	99	345	<10	100	11	75
May	53	250	65[a]	600[a]	75	335	<10	125	<10	60
June	100	435	35[a]	290[a]	49	165	--	---	3	55
July	113	520	32[a]	465[a]	63	265	5	115	4	95
Aug.	26	485	31[a]	320[a]	17	220	6	205	--	---
Sept.	23	360	41[a]	310[a]	16	175	6	150	--	---
Oct.	36	690	--	---	45	335	14	230	--	---
Nov.	53	1430	--	---	44	235	8	120	22	165
Dec.	69	900	48	640	24	95	11	115	20	130
1954										
Jan.	54	420	12	265					15	135
Feb.	51	870	23	330					8	45
Mar.	30	340	2	65					10	70
April	26	520	2	50					11	75
May	10	180	1	35					--	---
June	13	220	2	75					1	20
July	30	370	3	100					1	100
Aug.	21	200	2	85					1	75
Sept.	15	130	3	85					1	35
Oct.	22	240	4	135					1	25
Nov.	22	310	3	75					4	90
Dec.	30	250	5	140					8	80
					Simcoe, Ont.					
1955										
Jan.	31	230	8	135	1	55			18	130
Feb.	20	310	6	155	2	30			5	80
Mar.	17	200	4	120	1	25			1	100
April	45	450	6	135	1	25			1	60
May	28	350	9	170	2	35			1	35
June	20	210	12	325	1	25			2	55
July	23	150	13	205	2	50			2	40
Aug.	19	350	16	210					5	115
Sept.	19	560	13	540					3	90
Oct.	23	360	23	230					4	75
Nov.	25	180	30	285					4	100
Dec.	28	210	37	275					5	45

[a] Observations at McDougall & Sandwich, (Windsor Laboratory).

Table VII-33. Frequency Distribution of Sulfur Dioxide Concentrations at Recording Stations in Greater Windsor and Harrow - August 1953 to December 1954

Ranges of Concentration in Parts per Billion of Air

Month	Windsor High Pollution Area				Windsor Low Pollution Area				Harrow, Ontario			
	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200
1953												
Aug.	23.8	72.3	3.2	0.7	---	---	---	---	---	---	---	---
Sept.	28.6	69.1	2.2	0.1	---	---	---	---	---	---	---	---
Oct.	32.8	57.0	7.4	2.9	---	---	---	---	---	---	---	---
Nov.	31.4	55.5	8.6	4.6	13.6	81.6	4.0	0.7	29.6	69.4	1.0	---
Dec.	23.2	58.0	9.6	9.2	6.0	84.0	7.1	2.8	22.2	77.3	0.5	---
1954												
Jan.	21.3	60.8	14.9	2.9	54.2	44.2	1.4	0.1	29.4	70.5	0.1	---
Feb.	32.7	56.6	5.9	4.8	36.0	58.6	3.3	2.1	45.1	54.9	---	---
Mar.	30.5	64.9	4.3	0.3	80.8	19.2	---	---	42.5	57.5	---	---
Apr.	43.5	51.2	4.3	1.0	82.4	17.5	---	---	35.3	64.7	---	---
May	65.6	33.0	1.3	---	84.6	15.4	---	---	---	---	---	---
June	60.9	37.9	1.1	0.1	75.1	24.9	---	---	90.1	9.9	---	---
July	37.4	56.7	5.0	0.9	80.0	20.0	---	---	88.0	12.0	---	---
Aug.	20.1	79.2	1.0	---	83.2	16.8	---	---	90.7	9.2	---	---
Sept.	35.3	64.5	0.1	0.2	81.7	18.3	---	---	85.8	14.2	---	---
Oct.	10.6	87.8	1.4	0.2	76.7	23.0	0.3	---	89.4	10.6	---	---
Nov.	6.6	90.9	2.1	0.4	78.2	21.8	---	---	79.5	20.5	---	---
Dec.	6.2	89.4	3.8	0.5	68.8	30.7	0.5	---	55.7	44.3	---	---

Table VII-34. Frequency Distribution of Sulfur Dioxide Concentrations at Recording Stations in Greater Windsor and Harrow - January to December 1955

Ranges of Concentration in Parts per Billion of Air

Month	Windsor High Pollution Area				Windsor Low Pollution Area				Harrow, Ontario			
	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200	Percent Less than 10	Percent 10-109	Percent 110-200	Percent Above 200
1955												
Jan.	12.0	82.2	5.6	0.2	62.0	37.9	0.2	---	52.7	46.0	1.1	---
Feb.	22.5	75.4	1.6	0.6	62.1	37.6	0.3	---	70.9	29.1	---	---
Mar.	26.9	72.4	0.7	---	68.1	31.8	0.2	---	92.1	7.9	---	---
Apr.	3.5	84.3	8.3	4.0	69.9	28.8	0.2	---	85.3	14.7	0.1	---
May	19.3	74.9	4.3	1.5	61.3	37.4	1.3	---	87.4	12.6	---	---
June	15.7	83.0	1.2	0.1	58.4	40.0	1.5	0.1	77.2	22.8	---	---
July	25.3	74.5	0.3	---	28.3	70.4	1.3	---	63.0	37.0	---	---
Aug.	32.7	64.6	2.6	0.1	30.0	67.8	2.1	0.1	40.2	59.8	0.1	---
Sept.	36.7	60.7	2.0	0.6	28.9	69.1	1.6	0.4	47.1	52.9	---	---
Oct.	28.8	67.5	3.1	0.6	3.1	93.9	2.8	0.2	31.6	68.4	---	---
Nov.	21.3	74.6	4.1	---	2.6	92.5	4.6	0.3	31.4	68.6	---	---
Dec.	1.4	96.9	1.3	0.1	1.7	93.4	4.3	0.6	46.9	53.1	---	---

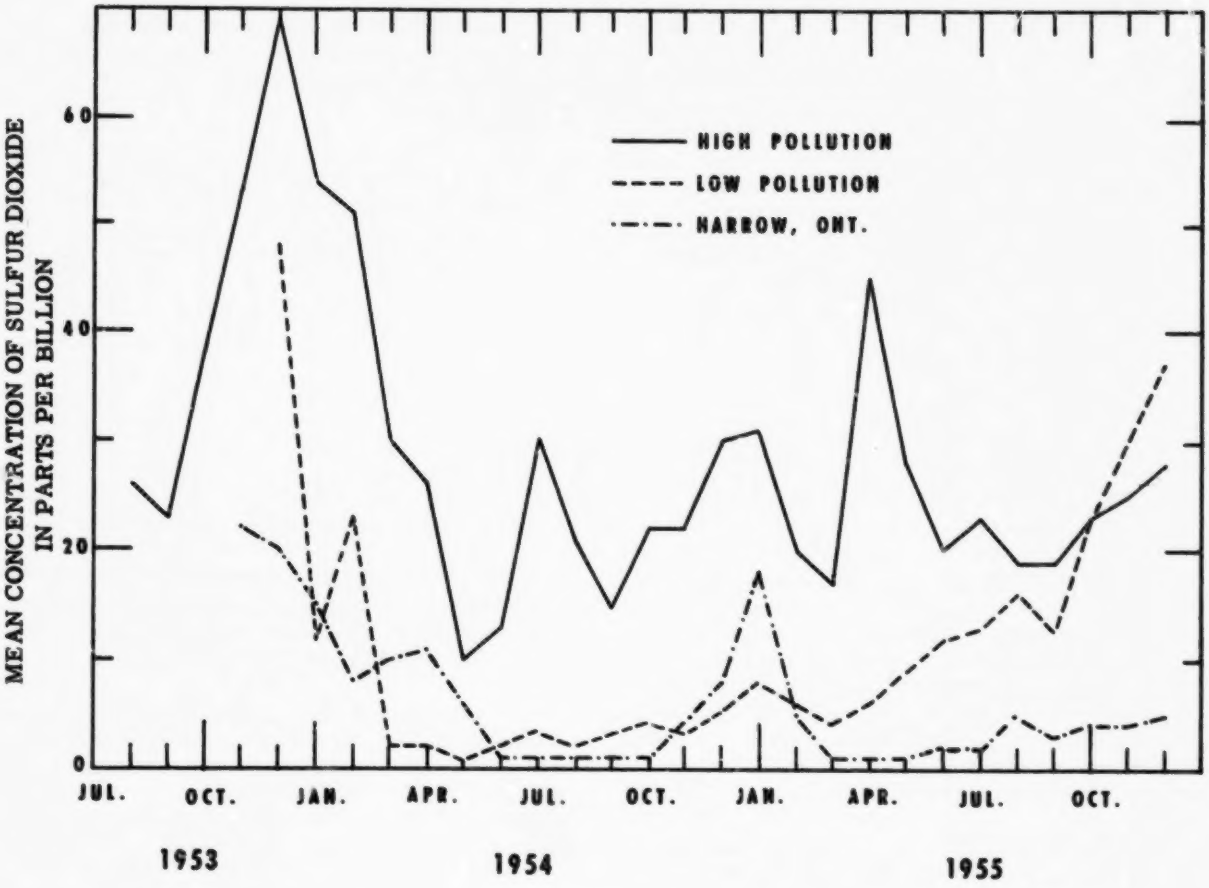


Figure VII-42. Monthly Mean Concentrations of Sulfur Dioxide in Canadian Study Areas

of the sulfur dioxide values were found to be lower than 109 p.p.b. and in only three months of this period, November and December 1953 and January 1955, did the concentrations attain a frequency of 0.5 to 1.1 percent in the range of 110-200 p.p.b.

There is no doubt that industrial and other activities on the United States side of the Detroit River have a strong influence on sulfur dioxide pollution levels in Windsor. This is apparent from an analysis of the relative frequency of occurrences of sulfur dioxide in various wind directions over the period 16 October, 1953, to 27 February, 1954, at a station in the Windsor high pollution area as shown by Table VII-35. By far the greatest frequency and highest concentrations occurred in periods of prevailing winds from the southwest and west involving sources of emission in Ecorse, River Rouge, Dearborn, Detroit, and from one power plant on the Windsor side. During the greater part of this test period, the Detroit River was free from Great Lakes shipping because of the close of the navigation season. The relatively large number of occurrences in south winds represent an apparent anomaly at first glance, since there are no sources to the south. However, the explanation is quite simple if meteorological factors are taken into account. As a result of the frictional drag of the earth's rotation, the wind direction tends to shift in a clockwise sense with increasing height above ground level. For typical hot emissions of waste gas containing sulfur dioxide from heavy industry stacks, the effective heights of the gas plumes may be several hundred feet higher than the physical heights of the stacks. Therefore, it may happen that at the

Table VII-35. Frequency of Various Sulfur Dioxide Concentrations with Wind Direction

Analysis of 4530 Observations of 30-Minute Average Concentrations
During Period October 16, 1953 to February 27, 1954
in Windsor High Pollution Area

Wind Direction	Total Observations	Percent frequency at indicated range of concentration in parts per billion						
		0-9	10-59	60-109	110-209	210-309	310-400	Above
N	339	50	29	15	5	--	--	--
NE	222	46	39	12	3	1	--	--
E	326	64	32	4	1	--	--	--
SE	323	89	10	0.3	0.3	--	--	--
S	861	38	41	13	6	1	0.5	0.5
SW	1087	5	27	23	20	12	7	4
W	1048	10	51	30	8	1	0.1	--
NW	322	10	52	23	13	3	--	--

time surface winds are from the south, the wind direction at the effective height of discharge or at plume height is from the southwest. Within the vicinity of the test station, the course of the Detroit River is almost north-south and this, coupled with the above clockwise shift, would tend to turn the surface wind as much as 20 to 35 degrees towards the southwest direction at, say, 300 feet above surface.

A comparison has been made of the mean values of sulfur dioxide pollution in the study area of two stations on the Detroit side with those of four stations on the Windsor side between November 19, 1953, and March 22, 1954. The data are shown in Table VII-36. The Detroit high pollution area showed over twice the average concentration of the Windsor high. In the Windsor low pollution area, the mean concentration was about one-third that of the high pollution area over this test period.

Table VII-36. Mean Sulfur Dioxide Concentrations in Health Study Areas - November 19, 1953 to March 22, 1954

Health Study Area	Mean Concentration parts per billion
Detroit, High Pollution Area 4	139
Detroit, Low Pollution Area 24	62
Windsor, High Pollution, Caron & Sandwich	57
Windsor, High Pollution, Peter & Chappell	64
Riverside, Low Pollution. . . .	22
Harrow, Ontario	15

An extended series of continuous observations were carried out with Thomas automatic analyzers in Detroit areas 4 and 24 for a period of about 2-1/2 years, commencing in the early summer of 1953. Detroit station 4 was located in the Highland Park - Hamtramck industrial-residential section, about 5 miles north of the Detroit River. Station 24 was located in a residential section near Oak Park, about 6 miles northwest of station 4. The above observations for the period July 1953 to April 1955 are summarized in Tables VII-37 and VII-38, in the form of six-hour monthly mean and maximum concentrations in parts per million for the four periods of the day.

Since area 4 is a relatively high pollution area, the mean and maximum concentrations were considerably higher, about two-fold, than those for comparable periods in area 24. Marked seasonal trends are evident, especially for area 4, in agreement with data for the Canadian sampling stations. The concentrations are much lower in the summer months than in the cold months of the year and, therefore, show the influence of the increased consumption of fuel during the heating season. Furthermore, there is evidence of a diurnal variation, the morning period of 0600-1130 shows the highest intensity of sulfur dioxide fumigations and there is also

Table VII-37. Monthly Mean and Maximum Concentrations of Sulfur Dioxide for Six-Hour Periods at Detroit Station 4

Month	Sulfur dioxide concentration expressed as parts per million								
	0000-0530		0600-1130		1200-1730		1800-2330		Monthly
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean
1953									
July	0.06	0.09	0.06	0.14	0.05	0.10	0.07	0.15	0.06
Aug.	0.07	0.11	0.06	0.14	0.04	0.10	0.08	0.19	0.06
Sept.	0.08	0.19	0.09	0.17	0.07	0.19	0.08	0.19	0.08
Oct.	0.10	0.26	0.12	0.40	0.08	0.27	0.11	0.23	0.11
Nov.	0.11	0.22	0.13	0.29	0.10	0.23	0.12	0.22	0.12
Dec.	0.12	0.29	0.14	0.35	0.11	0.34	0.13	0.37	0.13
1954									
Jan.	0.16	0.39	0.21	0.44	0.17	0.30	0.17	0.37	0.18
Feb.	0.14	0.23	0.17	0.37	0.12	0.32	0.16	0.35	0.15
Mar.	0.11	0.26	0.13	0.25	0.09	0.22	0.11	0.20	0.11
Apr.	0.10	0.20	0.11	0.24	0.08	0.18	0.10	0.26	0.10
May	0.09	0.16	0.08	0.16	0.06	0.10	0.08	0.16	0.08
June	--	--	--	--	--	--	--	--	--
July	0.02	0.03	0.02	0.03	0.01	0.02	0.01	0.02	0.02
Aug.	--	--	--	--	--	--	--	--	--
Sept.	0.06	0.10	0.06	0.16	0.06	0.12	0.06	0.11	0.06
Oct.	0.08	0.13	0.09	0.22	0.06	0.20	0.09	0.20	0.08
Nov.	0.09	0.19	0.12	0.28	0.09	0.21	0.10	0.18	0.10
Dec.	0.06	0.15	0.08	0.15	0.06	0.16	0.07	0.22	0.07
1955									
Jan.	--	--	--	--	--	--	--	--	--
Feb.	0.12	0.23	0.14	0.27	0.11	0.20	0.12	0.20	0.12
Mar.	0.11	0.32	0.11	0.28	0.07	0.16	0.12	0.21	0.10
Apr.	0.09	0.16	0.10	0.22	0.07	0.17	0.09	0.19	0.09

Table VII-38. Monthly Mean and Maximum Concentrations of Sulfur Dioxide for Six-Hour Periods at Detroit Station 24

Month	Sulfur dioxide concentrations expressed as parts per million								
	0000-0530		0600-1130		1200-1730		1800-2330		Monthly
	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean	Maximum	Mean
1953									
July	0.03	0.07	0.03	0.07	0.03	0.06	0.03	0.06	0.03
Aug.	0.04	0.08	0.04	0.07	0.03	0.06	0.03	0.08	0.03
Sept.	0.04	0.09	0.04	0.09	0.04	0.10	0.04	0.08	0.04
Oct.	0.04	0.09	0.04	0.07	0.04	0.08	0.05	0.10	0.04
Nov.	0.05	0.16	0.05	0.13	0.04	0.10	0.05	0.15	0.05
Dec.	0.05	0.09	0.06	0.16	0.05	0.12	0.06	0.16	0.05
1954									
Jan.	0.06	0.11	0.08	0.16	0.06	0.15	0.07	0.13	0.07
Feb.	0.07	0.16	0.08	0.17	0.06	0.13	0.07	0.12	0.07
Mar.	0.06	0.11	0.07	0.15	0.05	0.08	0.06	0.13	0.06
Apr.	0.04	0.13	0.06	0.15	0.05	0.10	0.04	0.10	0.05
May	0.05	0.09	0.05	0.08	0.04	0.10	0.05	0.12	0.04
June	--	--	--	--	--	--	--	--	--
July	0.03	0.06	0.03	0.06	0.03	0.04	0.03	0.06	0.03
Aug.	--	--	--	--	--	--	--	--	--
Sept.	0.04	0.12	0.03	0.07	0.04	0.09	0.04	0.13	0.04
Oct.	0.02	0.07	0.02	0.06	0.03	0.06	0.03	0.09	0.03
Nov.	0.05	0.22	0.05	0.11	0.05	0.30	0.06	0.38	0.05
Dec.	0.04	0.07	0.05	0.10	0.04	0.09	0.04	0.07	0.04
1955									
Jan.	--	--	--	--	--	--	--	--	--
Feb.	0.06	0.18	0.07	0.19	0.05	0.15	0.05	0.13	0.06
Mar.	0.05	0.17	0.04	0.10	0.04	0.10	0.05	0.17	0.04
Apr.	0.05	0.10	0.06	0.13	0.05	0.18	0.06	0.12	0.05

a secondary peak during the six-hour evening period from 1800-2330. At Station 4, the highest monthly six-hour mean attained a value of 0.21 p.p.m. in January 1954, with a monthly six-hour peak value of 0.44 p.p.m. The minimum values were 0.01 and 0.02 for monthly mean and maximum six-hour readings, in July 1954. The highest monthly mean concentration at Station 4 was about 0.18 (January 1954) in contrast to a high of 0.07 p.p.m. for the same month at Station 24.

The variation of sulfur dioxide concentration with time of day, or the trend in the daily cycle of pollution is well illustrated by the graphs in Figure VII-43, which represent conditions at the Detroit sampling station located in area 4. The observations cover the period from May to December, 1953.

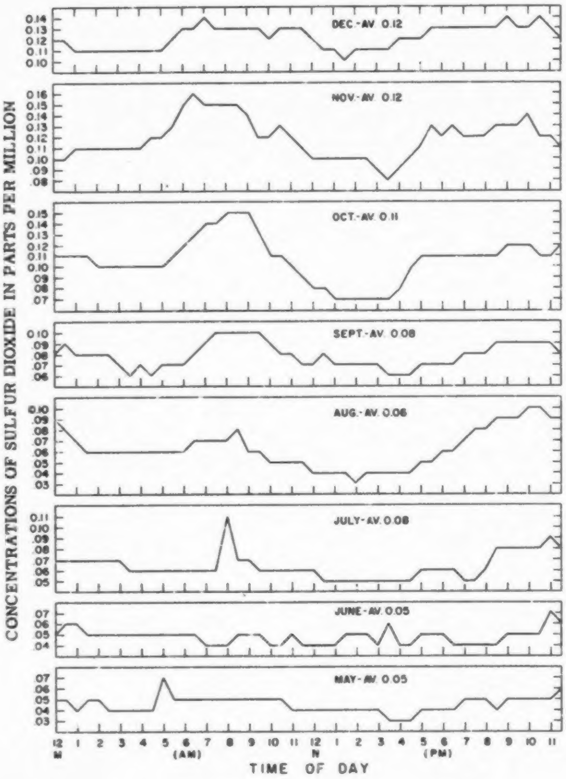


Figure VII-43. Variation of Sulfur Dioxide Concentrations with Time of Day at Detroit Station 4, May to December, 1953

Morning and night peaks in the daily cycle of pollution are clearly evident. Over the above test period these peaks are more pronounced during the fall months. Further discussion of the daily cycle of pollution is given in Chapter XI.

With regard to the frequency distribution of the six-hour mean values of sulfur dioxide concentrations in Detroit, a statistical analysis of six months' data at stations 4 and 24 for the latter half of 1953 yielded the results shown in Table VII-39. The data illustrate clearly the much greater intensity of sulfur dioxide fumigations in area 4.

Table VII-39. Frequency Distribution of Six-Hour Mean Concentrations of Sulfur Dioxide Recorded at Two Stations in Detroit, July to Dec., 1953

Concentration Range Parts per Million	Number		Percent	
	Station		Station	
	4	24	4	24
0.00 - 0.05	271	518	34	78
0.06 - 0.10	333	131	42	20
0.11 - 0.15	113	6	14	1
0.16 - 0.20	48	4	6	1
0.21 and Over	30	0	4	0
Total	795	649	100	100

Diurnal Variation of Sulfur Dioxide with Height

During March 1953, an interesting study was carried out to determine the influence of elevation on sulfur dioxide concentration levels by simultaneous observations at ground level and at a height of 125 ft. at two stations in the Majestic Building, Woodward and Michigan Streets, in the heart of the Detroit business district. The results are shown graphically in Figure XI-15 (Chapter XI), where the concentrations at the two levels are compared for each hour of the day.

The findings indicate that there is on the average about a 27 percent higher sulfur dioxide level at a height of 125 feet than there is at the ground. The three curves in the figure show approximately the same periodicity with a gradual rise to a maximum in the morning between 7 and 8 o'clock, a decrease to a minimum value in the late afternoon, and a gradual accumulation of SO_2 during the night period. Concentrations at 125 feet begin to decrease within an hour after sunrise. Those at ground level commence to decrease about an hour later. These results are in accord with the general principles of the diffusion of waste gas in the atmosphere, if it is assumed that the main sources of sulfur dioxide are emissions from stacks at elevations of several hundred feet above ground level. The effective heights of discharge would include the rise of the gas plume, which may be a considerable height above the source for discharges at high stack velocity, and temperature conditions.

OXIDANTS

Oxidant concentrations were measured at the Herman Kiefer Hospital in Detroit, both morning and afternoon, on a considerable number of days during the period July 1952 to November 1953 and from July 1954 to November 1954. In all, 260 analyses were made and the results are summarized in the frequency distribution Table VII-40.

Table VII-40. Frequency Distribution of Oxidant Concentrations at Detroit

Measured at Herman Kieffer Hospital during period July 1952 to November 1953, and July 1954 to November 1954

Class range of Oxidant expressed as Parts per hundred million of Ozone	Morning Period	Afternoon Period
	Percent	Percent
0.0 - 0.5	44.8	48.6
0.6 - 1.0	30.2	28.5
1.1 - 2.0	13.8	11.8
2.1 - 5.0	6.9	10.4
5.1 and Higher	4.3	0.7
	100.0	100.0
Number of Analyses	116	144
	Parts per hundred million	
Median	0.67	0.53
Mean	1.36	0.83
Minimum.	0.00	0.00
Maximum	26.60	5.88

Over 75 percent of the measurements were in the concentration range of 0.0 to 1.0 parts per hundred million of air (p.p.h.m.). About 7 percent of the morning observations and about 10 percent of the afternoon observations were in the range of 2.1 to 5.0 p.p.h.m. The highest concentrations were recorded in the morning period. The median concentration was slightly higher for the morning period. The mean values have been influenced considerably by the exceptionally high observations recorded in September 1952 during a severe smog period lasting several days. Coincident with these high oxidant values, there were corresponding increases in the levels of particulate and sulfur dioxide pollution.

In general, oxidant concentrations in the Detroit River area are much lower than the levels prevailing in the Los Angeles area.

ALDEHYDES

The atmospheric concentrations of aldehydes were investigated on an occasional basis by analyses at the Windsor Laboratory over a period of about 9 months. This sampling site is located at the corner of Sandwich and McDougall Streets, fronting one of the main thoroughfares near the Detroit River. As shown in Table VII-41, the median concentration was 0.06 p.p.m. with a maximum value of 0.85 p.p.m. About 49 percent of the values were in the range of 0.0 - 0.05 p.p.m. The concentrations observed were not normally distributed and the mean value of 0.20 p.p.m. is influenced considerably by the frequency distribution of about 31 percent of values recorded above 0.30 p.p.m.

Aldehydes represent a component of the exhaust gases from internal combustion engines, particularly from the exhaust of diesel trucks and busses. Atmospheric concentrations are greatly dependent upon the density of traffic and its pattern in relation to weather factors.

NITROGEN DIOXIDE

Three automatic samplers, with intake leads connected to a common manifold, were operated at the Windsor Laboratory station to determine, concurrently, the levels of nitrogen dioxide and sulfur dioxide by conductimetric and colorimetric procedures. In all, 157 samples of air were analyzed for nitrogen dioxide with the results as indicated in Table VII-42.

Table VII-41. Frequency Distribution of Aldehyde Concentrations Found in the Windsor Area - October 24, 1952 to August 14, 1953

Aldehyde Parts per million	Frequency	
	Number	Percent
0.00 - 0.05	25	49.0
0.06 - 0.10	5	9.8
0.11 - 0.30	5	9.8
0.31 - 0.50	9	17.7
0.51 and higher	7	13.7
Total Number of Analyses	51	100.0
	Parts per million	
Median	0.06	
Mean	0.20	
Maximum	0.85	
Minimum.	0.00	

Total number of positive determinations (excluding trace values) 29.
Mean of positive determinations 0.35 p.p.m. (Trace was taken as equivalent to 0.01 p.p.m.).

Table VII-42. Frequency Distribution of Nitrogen Dioxide Concentrations Found in the Windsor Area for 13 Days in September to November, 1955

Nitrogen Dioxide Parts per hundred million	Frequency	
	Number	Percent
1.0 - 1.9	11	7.0
2.0 - 2.9	49	31.2
3.0 - 3.9	54	34.4
4.0 - 4.9	21	13.4
5.0 - 5.9	5	3.2
6.0 - 6.9	8	5.1
7.0 - 7.9	7	4.5
8.0 - 8.9	2	1.2
Totals	157	100.0
	Parts per hundred million	
Mean	3.6	
Maximum	8.8	
Minimum	1.5	

The concentrations were uniformly of a low order of magnitude and were confined to a relatively small range. However, from the limited data available, it may be concluded that the hourly nitrogen dioxide levels fluctuated in a manner similar to those of sulfur dioxide, but were of lower magnitude than the conductrimetric sulfur dioxide levels.

The colorimetric sulfur dioxide determinations, based on the chromogenic reaction of fuchsin, formaldehyde and sulfite, yielded consistently lower values than the conductimetric analyses and the difference could be partially accounted for by the presence of nitrogen dioxide in the atmosphere and its reaction with the fuchsin reagent to lower the colorimetric sulfur dioxide value.

OTHER GASEOUS CONTAMINANTS

Other gaseous contaminants that have been noted in this study area are hydrogen sulfide, chlorine and ammonia. A limited survey carried out in the Windsor area in 1951, when samples were collected and analyzed on an occasional basis, yielded the following results.

Contaminant	No. of Samples	Concentration Parts per million	
		Mean	Maximum
Hydrogen sulfide	49	0.11	0.61
Chlorine . . .	48	0.10	0.62
Ammonia . . .	41	0.22	3.07

The number of samples is insufficient for purposes of comparison with other major contaminants, but serves to indicate the variety of gases that may be found in the atmosphere of the study area. An industrial plant that served as a prominent source of chlorine and ammonia in the area ceased to operate in 1952. Hydrogen sulfide is derived from both industrial and natural sources.

STUDY OF AIR-BORNE BACTERIA

The Communicable Disease Center of the Public Health Service conducted a study of bacterial particulates in the extramural air of the Detroit Area. Sampling equipment and methods are described. Figures were given for air-borne bacterial levels during different times of day, different days, and at three different locations in Detroit. No consistent relationship between bacterial counts and total particulate matter or sulfur dioxide concentrations were found. Suggestions for future bacteriological studies of the atmosphere were made. The report of this work was entitled, "Air-Borne Bacteria Studies In The Detroit, Michigan Area." December 1952 to August 1953, Final Report, CD 3-1633.

SUMMARY

Most of the data relate to coarse and fine particulate matter, the complexity of its composition, and to sulfur dioxide. Other gases investigated, to a limited extent, have included ozone or oxidants, nitrogen dioxide, aldehydes and fluoride. In general, it can be stated that the concentration levels of the major contaminants fluctuate over a relatively wide range, as influenced by weather factors, seasonal and daily cycles. Levels of particulate matter and sulfur dioxide are of the order that can be expected for heavily industrialized cities of similar size.

The dustfall rates in the study area vary considerably from industrial to residential and suburban neighborhoods and are as high as those reported for New York, Chicago and some other large cities, if due allowance is made for differences due to the shape and size of collectors employed to recover the fall-out(18).

Air-borne particulate matter within the study area also varies over a considerable range in concentration, and in this respect the mean and maximum levels rank with those found in New York, Chicago, Philadelphia and other cities of over two million population(10). The inorganic fraction of this suspended dust contains about twenty metal and other elements, of which the most abundant are calcium, silicon, aluminum and iron. Next in order of abundance are magnesium, lead, copper, zinc and manganese. Other elements which were found only in relatively small quantities are titanium, tin, molybdenum, barium, nickel, vanadium, chromium, cadmium and beryllium. Many of these elements exist in the dust as oxides, sulfates and carbonates, along with chlorides, fluorides and nitrates. The median size of air-borne particulates in the study area is about 0.9 micron. The organic fraction is also extremely complex in character, and contains both aliphatic and aromatic hydrocarbons and other compounds, including a number of polycyclic aromatic hydrocarbons which may possess carcinogenic properties.

The extensive studies of sulfur dioxide reveal mean and maximum concentration levels that are comparable to some areas of New York City, such as Staten Island and Brooklyn, according to fairly comprehensive data for 1956, reported by the Interstate Sanitation Commission representing New York, New Jersey and Connecticut (98). Most of the studies on sulfur dioxide in other cities relate to limited surveys and it is, therefore, difficult to compare such data with Windsor-Detroit. Monthly means in the study area, however, rank with some sections of Chicago and other heavily industrialized communities, including Baltimore and Cincinnati, as reported by Cholak(13).

Both seasonal and diurnal trends have been manifested in the sulfur dioxide pollution levels. A pronounced seasonal trend has also been exhibited by dustfall rates, ascribed to the increased consumption of fuel during the heating season, as with sulfur dioxide. Smoke and haze concentrations, as reflected by Coh values per 1000 linear feet of air, also vary seasonally, with much higher values recorded in the cold months than in the warm months of the year. Weight concentrations of air-borne particulates, as determined by sampling with high volume filtration instrument, show an anomalous trend in that the concentrations tend to rise in the late spring, summer and fall months.

The levels of major contaminants in the study area are decreasing from the relatively high values of 1951 and 1952. This decrease is due to a variety of factors of which the principal one may be the decreased consumption of solid fuel and its replacement by fuel oil and natural gas. Other reasons may include the more stringent application of control measures at the local level, coupled with the reduction in smoke emissions from vessel traffic on the Detroit River.

This study has not revealed any abnormal oxidant or nitrogen dioxide levels or smog-forming by-products from the photochemical inter-action of hydrocarbons with such contaminants. Although eye-irritating pollutants have been reported occasionally, the photochemical reactions responsible for the build-up of troublesome smog conditions in Los Angeles, (27) aggravated by its adverse topographical and meteorological features, have not, as yet, reached a significant level in Detroit-Windsor. However, as the density of motor vehicle traffic continues to increase in heavily populated communities, the problem of smog formation through photochemical interaction of atmospheric waste products will assume increasing importance in such urban areas.

Chapter VIII

EFFECTS OF POLLUTION ON HEALTH

INTRODUCTION

For some years it has been known that under certain extraordinary circumstances air pollution can cause illness and death. This is especially true with respect to persons in older age groups and those who suffer from some type of cardiac or respiratory condition. In three notable instances air pollution has been associated with the death of people:

1. The Meuse Valley, Belgium incident in 1930, when 80 persons died and hundreds were made ill by breathing air heavily laden with an accumulation of atmospheric impurities(1).

2. The Donora, Pennsylvania episode in October of 1948, when 20 people died and nearly 6,000 were made ill during a four-day period when adverse topographical and meteorological conditions permitted the accumulation of atmospheric pollutants(61).

3. The London, England smog episode in December of 1952, which resulted from an accumulation of all types of urban area pollutants when meteorological conditions for dispersion of pollutants were very unfavorable. In this episode, approximately 4,000 more deaths occurred than would be expected in a time period of like duration with usual atmospheric conditions(79).

There is little controversy in these three instances that unusually high air pollution levels were an important factor in the resulting deaths and illnesses. However, almost no information is available from which to appraise the probable effects of air pollution on health under the conditions which usually exist in the Detroit-Windsor area or in similar urban communities. Studies were therefore conducted to determine whether or not the health of people residing in the area was being adversely affected by air pollution.

OBJECTIVES

Since almost no previous work had been done with regard to the effects of air pollution on health, suitable methodology was not available for use in conducting studies in the Detroit-Windsor area. Therefore the major objective was to develop, use, and evaluate methods and techniques for appraising the possible deleterious effects of air pollution on health. The secondary objective was to determine whether the incidence of illness among persons residing in areas of higher pollution varied from that of persons residing in areas of lower pollution and if so, in what catagories of illness.

In addition to these two principal objectives, it was felt that in designing the study, as many of the following questions as possible should be kept in mind:

a. Is the incidence of illness related to the degree of over-all pollution or to specific contaminants in the air?

b. If there are differences in morbidity rates in lower and higher pollution areas, are these differences related to sex, age, occupation, or socio-economic factors?

c. Do people who have lived for some years in areas of higher pollution suffer to a greater degree from chronic illness than people who have lived in areas of lower pollution?

d. Do people who lived in a polluted area develop a tolerance level below which there is little or no effect from air pollution?

e. Do relatively low levels of pollution, as contrasted with "smog" episodes, exert a detrimental effect on the health of people exposed to them over a long period of time?

f. Is the mortality rate greater in areas of higher pollution than in areas of lower pollution, and are there differences in the average age at death of adults living in such areas?

g. Do people who suffer from chronic upper respiratory diseases appear more sensitive to air pollution than persons who are not so afflicted?

HOUSEHOLD MORBIDITY STUDY

INTRODUCTION

The most important portion of the over-all program for the study of the possible effects of air pollution on health was a household morbidity survey. This study consisted of the collection of information concerning sickness rates experienced by matched groups of people living in areas subjected to varying degrees of air pollution. Notes concerning sicknesses were made daily by members of participating households, and more detailed information concerning sicknesses (and other information) was collected by enumerators in biweekly personal visits. Control areas were used where nearly no air pollution existed. Air pollution measurements were made throughout the study. A discussion of planning considerations has been presented by A.F.W. Peart and G.H. Josie(57).

The morbidity study was carried out simultaneously in Canada and the United States. Similar questionnaire forms, enumerator training programs, and methods and techniques were used in both countries. To as complete a degree as possible, uniformity was maintained throughout the field work.

The study was designed to test the following hypotheses:

a. The health status of people living for long periods in areas of high pollution is adversely affected in comparison with people living in areas of low pollution;

b. Persons exhibit symptomatic response to peak episodes of pollution (short periods of extreme concentrations).

ORGANIZATION AND STAFF

The Joint Technical Advisory Board requested the cooperation of several governmental agencies both in the United States and Canada. Activities in the United States portion of the health study were conducted primarily by the City of Detroit Department of Health. Funds were made available from the Department's regular budget for employing five full-time enumerators and the Industrial Hygiene staff was, in part, diverted to activities in environmental air pollution measurements. The Statistical Division analyzed the data. The Detroit Bureau of Smoke Inspection and Abatement contributed substantially to the study, especially in making an appraisal of air pollution emissions from industrial plants in various portions of the City of Detroit.

The organization of the Canadian study rested within the Department of National Health and Welfare, Ottawa. The Division of Epidemiology of the Department was chiefly responsible for planning and directing the field operation. Close operation with both the Research and Statistics Division and the Occupational Health Division of the Department was maintained. The work of analyzing the data was done primarily by the Research and Statistics Division, while over-all coordination of the study was provided by the Occupational Health Division. The field work, for administrative purposes, was under the Industrial Hygiene Division of the Ontario Department of Health. The Health Department of the City of Windsor cooperated in many ways and made available office accomodations. In the control areas of Kingsville, Harrow and Simcoe, the part-time Medical Officers of Health cooperated in every way. The Technical Advisory Board staff at the Windsor Laboratory provided instruments for measuring pollution in areas selected for the health study. The full-time staff of the Canadian part of the health study consisted of two supervisors, one responsible for administration and the other for enumerators. The enumerators were employed on a part-time basis and their number varied from 18 to 25. The latter figure was reached during the second year of study with the addition of the town of Simcoe as a control area. In all, ten enumerators were used in Windsor, and four each in Kingsville and Harrow. When Simcoe was added during the second year, seven additional enumerators were engaged.

SELECTION OF STUDY HOUSEHOLDS IN CANADA

Measurements of dustfall, total suspended particulate matter, and sulfur dioxide made over a two-year period were used as the basis for selecting portions of the Windsor area which could be designated as "high pollution" and "low pollution" (Figure VIII-1). After the area selections were made on the basis of prevailing pollution levels, the Dominion Bureau of Statistics gave assistance in the selection of sample households. Analysis of census data for both areas indicated that random samples of the population in these areas would differ radically because families in the low pollution area were younger, earned higher salaries, and had a greater number of children in lower age groups. In view of this, the 200 families required from each of the areas were selected on a socio-economic basis, one-half from the above-average assessment stratum and the other half from below-average. In addition, both samples were restricted to identical family-size distributions. After family selections had been made, initial calls were made by the enumerators to introduce the study and to collect current information on the number, age, and sex of the occupants of each household, the time of their last visit to a physician, their physical maladies, their education and employment status, the number of rooms in the household, and whether the occupant owned or rented the dwelling. These data were compared on an area basis and all households which did not fall within the same general pattern established for both areas were replaced.

In addition to the 400 households selected for study in Windsor, control areas were established in Kingsville and Harrow, located about 40 and 25 miles distant respectively from Windsor. These two towns were chosen because air pollution measurements had demonstrated they were exposed to appreciably lower pollution levels than were the Windsor areas. The households used for study in the control areas were select-

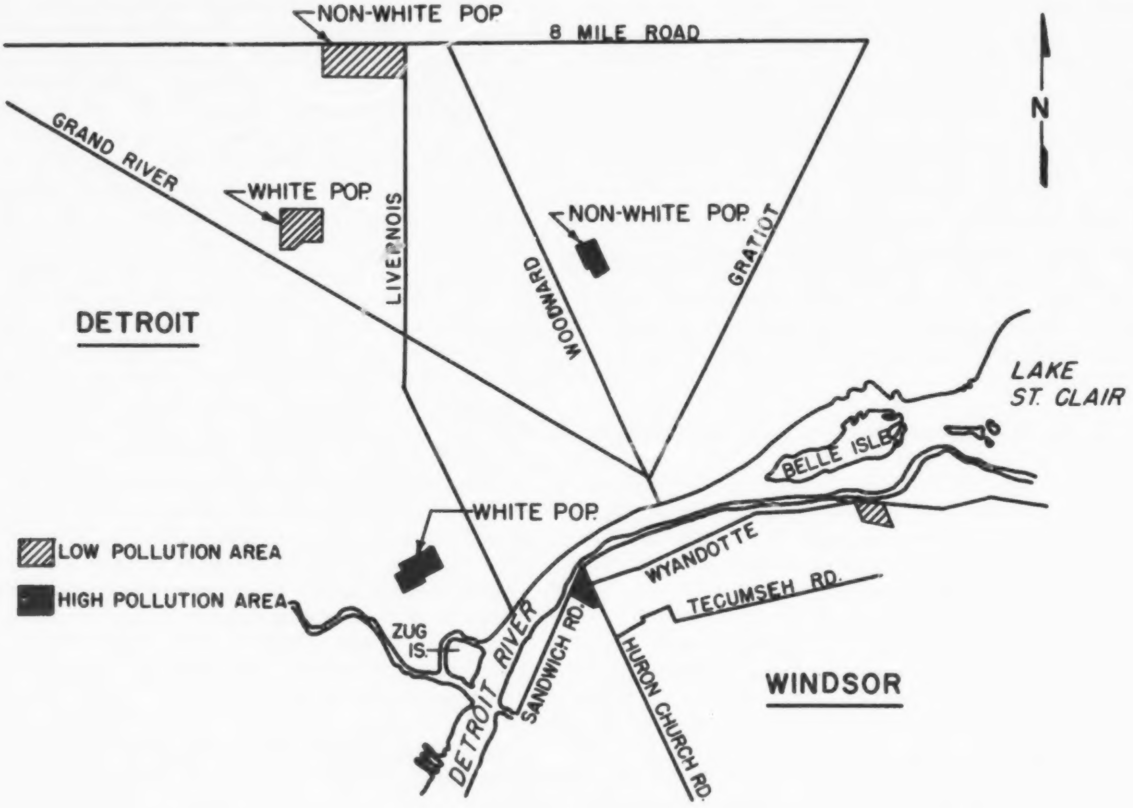

NON-WHITE POP
8 MILE ROAD
N
GRAND RIVER
WHITE POP
LIVERNOIS
NON-WHITE POP
WOODWARD
GRATIOT
DETROIT
LAKE ST. CLAIR
BELLE ISLE
WHITE POP
▨ LOW POLLUTION AREA
■ HIGH POLLUTION AREA
WYANDOTTE
TECUMSEH RD.
ZUG IS.
DETROIT RIVER
SANDWICH RD.
HURON CHURCH RD.
WINDSOR

Figure VIII-1. Location of Health Study Areas

ed by the same method as used in Windsor, i.e., from assessment levels. An effort was also made to have these households fall within the pattern of sample established in Windsor. Where this failed to materialize on first selection, substitutions were made by elimination of households having very high or very low assessment values. One hundred households were selected in each town. When added to the 400 selected in the Windsor areas, a total of 600 households had been selected for study during the first year.

On conclusion of the first year of study, a preliminary analysis of the data indicated sickness was more prevalent in the Kingsville and Harrow areas than in Windsor. In view of these preliminary findings, a second control area was added to the study, the town of Simcoe, 160 miles from Windsor. To ensure that the selection of Simcoe meant the addition of an area relatively free of air pollution, air sampling tests were conducted. These tests indicated that the area was definitely one of low pollution when compared with Windsor. On establishing this fact, the sample of 200 households required for study was selected randomly from census lists. On their first visits the enumerators learned that too many elderly families had been drawn into the sample. Twenty-five families therefore were replaced, the replacement families being chosen by random selection from a list also compiled from the latest census data.

In all areas under study, additional families were listed to make allowance for loss by noncooperation or families moving away. This ensured that the number of households in the sample would be maintained at 200 for each area. The addition of Simcoe to the survey raised the total number of households under study for the second year to 800.

SELECTION OF STUDY HOUSEHOLDS IN THE UNITED STATES

In the spring of 1951, 28 out of 369 census tracts in Detroit were selected for evaluation of degree of air pollution. Selection of these areas was based on preliminary 1950 census data, number of relief cases, economic rating based on the 1946 economic survey, and location and nature of industrial plants and effluents from them. The objective was to select matched population groups in areas differing as sharply as possible in degree of air pollution.

The actual pollution levels in these 28 census tracts were then appraised by making measurements of total suspended particulate matter in the air at 31 stations in the 28 census tracts.

By fall of 1952, sufficient preliminary work had been done to begin the study of the effects of pollution on health. Since changes might have occurred in Detroit since the 1946 economic census, and the 1950 general census, a tour was made of all areas found to have significantly high or low pollution levels. Housing characteristics, maintenance of property or neighborhood, character of shopping districts, number and characteristics of individuals seen on the streets, and in stores, schools, and churches, and other factors were compared from area to area. Census tracts 60 and 260 (Figure VIII-1) were selected to represent high and low pollution areas respectively. These two areas consist of an almost exclusively middle socio-economic class white population.

Only one area having nonwhite population (census tract 305) and low air pollution was available. Since one of the objectives of the health study was to determine possible differences in racial response to air pollution, this area was accepted. None of the nonwhite communities with high pollution matched the socioeconomic characteristics of the residents in census tract 305. Nevertheless, census tracts 554, 555, and 556, all very small, were selected as having similar differences in population characteristics from tract 305 and the greatest difference in air pollution. It was hoped that knowledge of the socio-economic difference between the two nonwhite groups could be taken into account in determining variation of the effects of air pollution on health.

Within the census tracts chosen for study, a sampling was made of the specific dwelling units to be included. This was done in accordance with generally accepted statistical sampling techniques. Dwelling units over stores were rejected and replaced since their occupants are too transient. As the study proceeded, occupants of selected units who moved within the study area were followed and their original dwelling unit was dropped. If the occupants moved away from the area, the occupants were dropped from the study and the new occupants of the dwelling unit included.

Addresses and apartment numbers for the

selected units and names of the occupants were obtained, and introductory letters were mailed. Enumerators made their initial visits, soon after receipt of these letters, to obtain socio-economic and health data and answers to a modified Cornell Medical Index Questionnaire. Less than ten percent of the selected families refused to participate in the study.

To test the dwelling unit sampling technique, the socio-economic data elicited from the study group were compared with data contained in the 1950 census released for Detroit. Results of the comparison were excellent for three areas. Data collected in census tracts 554, 555, and 556 showed marked differences from census data. A review of these areas indicated that the sampling procedure was not at fault. During the years following the census, large areas elsewhere had been demolished for housing projects. Persons displaced had moved into the areas under study, while those residents living in tracts 554, 555, and 556 at the time of the census, had moved elsewhere. However, the three tracts were considered satisfactory as a high pollution area populated by nonwhite residents.

It may be concluded that the two predominantly white population areas were similar except for the degree of air pollution. The nonwhite areas for study and control purposes were dissimilar for degree of air pollution as well as certain other environmental conditions.

Although 150 units had been chosen in each of the four United States study areas, personnel limitations necessitated reduction of the number of units under study in the two areas having a white population to 90 each. About 10 percent of the residents in the two areas having a white population and about 20 percent in the areas with a nonwhite population were under study.

HEALTH STATUS OF PERSONS BEING STUDIED

It was considered useful to have, at the commencement of the study, a picture of the state of health of all persons participating. This established state of health would later be compared with that existing at the conclusion of the study. In other words, a baseline of health would be established, deviations from which would be compared between and within areas of different pollution levels, either on a seasonal basis or over an extended period of time. For this purpose, the Cornell Medical Index was used.

The Cornell Medical Index Questionnaire consists of 201 symptom questions to be answered by the individual by circling "yes" or "no". These symptom questions are grouped into disease categories. The procedure of analysis is to evaluate the "yes" and "no" answers within the categories and thereby obtain information as to whether or not the individual may be suffering from the condition concerned. The questionnaire was originally designed for use in outpatient clinics of hospitals where confirmation of diagnosis could later be provided through a complete physical examination. In this study, it was not feasible to conduct the physical examination. Since a number of the questions in the Cornell Medical Index are of a phsychosomatic nature and might have proved embarrassing to some of the persons under study, such questions were eliminated. After modification, 78 questions remained (Table VIII-1). In the case of children under 16 years of age, a similar questionnaire was filled out by the enumerator, who queried a parent or other responsible person. All adults, if capable, filled out the questionnaire themselves. After pretesting, the questionnaire was used at commencement of the study in August 1953 for all individuals participating. It was again filled out during January 1955. In this final survey, the 123 questions originally eliminated were asked (Table VIII-2). No great difficulty was encountered either time in obtaining approximately 95 percent cooperation in completing the questionnaire.

PRETEST OF FORMS AND FIELD TECHNIQUES

In order to test the various forms and field techniques to be used in the study, preliminary field trials were made(56). The pretest, conducted on 150 families over a period of a month, was undertaken to establish, under actual field conditions the efficiency of the individual health questionnaire, household record card, individual sickness record, and calendar designs to be used as memory aids for families, and to determine the most suitable periodicity for enumerators' visits. At the conclusion of the pretest each enumerator reported on family response, general procedures, and other points of value to the main study. As a result of the pretest the following forms and techniques, in addition to the modified Cornell Medical Index, were selected:

Table VIII-1. Questions Used in the Modified Cornell Medical Index

1. Do your eyes continually blink or water?
2. Do you often have bad pains in your eyes?
3. Are your eyes often red or inflamed?
4. Are you hard of hearing?
5. Have you ever had a running ear?
6. Do you have constant noises in your ears?
7. Are you often troubled with bad spells of sneezing?
8. Is your nose continually stuffed up?
9. Do you suffer from a constantly running nose?
10. Have you at times had bad nose bleeds?
11. Do you have to clean your throat frequently?
12. Do you often feel a choking lump in your throat?
13. Do you often catch severe colds?
14. Do you frequently suffer from heavy chest colds?
15. When you catch a cold, do you always have to go to bed?
16. Do frequent colds keep you miserable all winter?
17. Do you get hay fever?
18. Do you suffer from asthma?
19. Are you troubled by constant coughing?
20. Have you ever coughed up blood?
21. Do you sometimes have severe soaking sweats at night?
22. Have you ever had a chronic chest condition?
23. Have you ever had T. B. (Tuberculosis)?
24. Did you ever live with anyone who had T.B.?
25. Has a doctor ever said your blood pressure was too high?
26. Has a doctor ever said your blood pressure was too low?
27. Do you have pains in the heart or chest?
28. Are you often bothered by thumping of the heart?
29. Does your heart often race like mad?
30. Do you often have difficulty in breathing?
31. Do you get out of breath long before anyone else?
32. Do you sometimes get out of breath just sitting still?
33. Are your ankles often badly swollen?
34. Do cold hands or feet trouble you even in hot weather?
35. Do you suffer from frequent cramps in your legs?
36. Has a doctor ever said you had heart trouble?
37. Does heart trouble run in your family?
38. Is your tongue usually badly coated?
39. Is your appetite always poor
40. Do you often suffer from upset stomach?
41. Are you often sick to your stomach?
42. Do you suffer from indigestion?
43. Do severe pains in the stomach often double you up?
44. Do you suffer from constant stomach trouble?
45. Has a doctor ever said you had stomach ulcers?
46. Do you suffer from frequent loose bowel movements?
47. Have you ever had severe bloody diarrhea?
48. Do you constantly suffer from bad constipation?
49. Have you ever had serious liver or gall bladder trouble?
50. Are you crippled with severe rheumatism, (arthritis)?
51. Is your skin very sensitive or tender?
52. Does your face often get badly flushed?
53. Do you sweat a great deal even in cold weather?
54. Are you often bothered by severe itching?
55. Does your skin often break out in a rash?
56. Are you often troubled with boils?
57. Do you suffer badly from frequent severe headaches?
58. Does pressure or pain in the head often make life miserable?
59. Are headaches common in your family?
60. Do you often have spells of severe dizziness?
61. Were you ever treated for severe anemia, (thin blood)?
62. Do you usually get up tired and exhausted in the morning?
63. Are you frequently ill?
64. Are you frequently confined to bed by illness?
65. Are you always in poor health?
66. Are you considered a sickly person?
67. Do severe pains and aches make it impossible for you to do your work?
68. Did you ever have scarlet fever?
69. As a child, did you have rheumatic fever, growing pains or twitching of the limbs?
70. Do you have diabetes, (sugar disease)?
71. Did a doctor ever treat you for tumor or cancer?
72. Are you definitely underweight?
73. Are you definitely overweight?
74. Do you often have small accidents or injuries?
75. Do you usually have great difficulty in falling asleep or staying asleep?
76. Do you smoke more than 20 cigarettes a day?
77. Do you drink more than six cups of coffee or tea a day?
78. Do you usually take two or more alcoholic drinks a day?

Table VIII-2. Questions from Cornell Medical Index which were Eliminated in the Initial Survey but Used in the Final Survey

79. Do you need glasses to read?
80. Do you need glasses to see things at a distance?
81. Has your eyesight often blacked out completely?
82. Have you lost more than half your teeth?
83. Are you troubled by bleeding gums?
84. Have you often had severe toothaches?
85. Do you usually eat sweets or other food between meals?
86. Do you always gulp your food in a hurry?
87. Do you usually feel bloated after eating?
88. Do you usually belch a lot after eating?
89. Does stomach trouble run in your family?
90. Were you ever troubled with intestinal worms?
91. Have you ever had piles, (rectal hemorrhoids)?
92. Have you ever had jaundice, (yellow eyes and skin)?
93. Are your joints often painfully swollen?
94. Do your muscles and joints constantly feel stiff?
95. Do you usually have severe pains in the arms or legs?
96. Does rheumatism, (arthritis), run in your family?
97. Do weak or painful feet make your life miserable?
98. Do pains in the back make it hard for you to keep up with your work?
99. Are you troubled with a serious bodily disability or deformity?
100. Do cuts in your skin usually stay open a long time?
101. Do you have hot or cold spells?
102. Do you frequently feel faint?
103. Have you fainted more than twice in your life?
104. Do you have constant numbness or tingling in any part of your body?
105. Was any part of your body ever paralyzed?
106. Were you ever knocked unconscious?
107. Have you at times had a twitching of the face, head or shoulders?
108. Did you ever have a fit or convulsion, (epilepsy)?
109. Has anyone in your family ever had fits or convulsions (epilepsy)?
110. Do you bite your nails badly?
111. Are you troubled by stuttering or stammering?
112. Are you a sleepwalker?
113. Are you a bedwetter?
114. Were you a bedwetter between the ages of 8 and 14?
115. Have you ever had anything seriously wrong with your genitals, (privates)?
116. Are your genitals often painful or sore?
117. Have you ever had treatment for your genitals?
118. Has a doctor ever said you had a hernia, (rupture)?
119. Have you ever passed blood while urinating, (passing water)?
120. Do you have trouble starting your stream when urinating?
121. Do you have to get up every night and urinate?
122. During the day, do you usually have to urinate frequently?
123. Do you often have severe burning pain when you urinate?
124. Do you sometimes lose control of your bladder?
125. Has a doctor ever said you had kidney or bladder disease?
126. Do you often get spells of complete exhaustion or fatique?
127. Does working tire you out completely?
128. Does every little effort wear you out?
129. Are you constantly too tired and exhausted even to eat?
130. Do you suffer from severe nervous exhaustion?
131. Does nervous exhaustion run in your family?
132. Do you come from a sickly family?
133. Do you wear yourself out worrying about your health?
134. Are you always ill and unhappy?
135. Are you constantly made miserable by poor health?
136. Did you ever have malaria?
137. Were you ever treated for "bad blood" (venereal disease)?
138. Did a doctor ever say you had a goiter, (in neck)?
139. Do you suffer from any chronic disease?
140. Did a doctor ever say you had varicose vains (swollen vains) in your legs?
141. Did you ever have a serious operation?
142. Did you ever have a serious injury?
143. Do you find it impossible to take a regular rest period?
144. Do you find it impossible to take regular daily exercise?
145. Do you sweat or tremble a lot during examinations or questioning?
146. Do you get nervous and shaky when approached by a superior?
147. Does your work fall to pieces when the boss or a superior is watching you?
148. Does your thinking get completely mixed up when you have to do things quickly?
149. Must you do things very slowly in order to do them without mistakes?
150. Do you always get directions and orders wrong?
151. Do strange people or places make you afraid?

Table VIII-2. (Cont'd.)

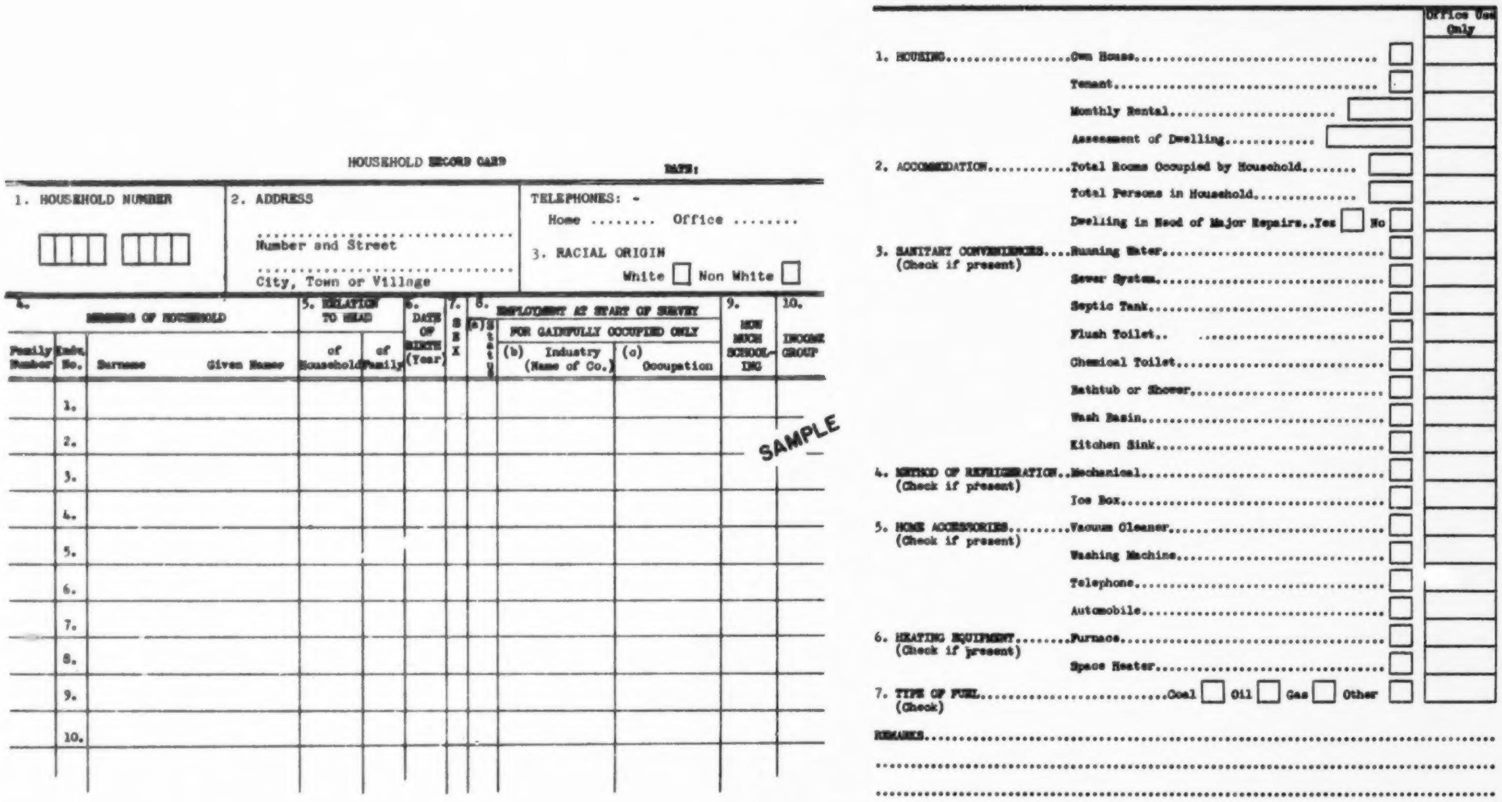
152. Are you scared to be alone when there are no friends near you?
153. Is it always hard for you to make up your mind?
154. Do you wish you always had someone at your side to advise you?
155. Are you considered a clumsy person?
156. Does it bother you to eat except in your own home?
157. Do you feel alone and sad at a party?
158. Do you usually feel unhappy and depressed?
159. Do you often cry?
160. Are you always miserable or blue?
161. Does life look entirely hopeless?
162. Do you often wish you were dead and away from it all?
163. Does worrying continually get you down?
164. Does worrying run in your family?
165. Does every little thing get on your nerves and wear you out?
166. Are you considered a nervous person?
167. Does nervousness run in your family.
168. Did you ever have a nervous breakdown?
169. Did anyone in your family ever have a nervous breakdown?
170. Were you ever a patient in a mental hospital (for your nerves)?
171. Was anyone in your family ever a patient in a mental hospital (for their nerves)?
172. Are you extremely shy or sensitive?
173. Do you come from a shy or sensitive family?
174. Are your feelings easily hurt?
175. Does criticism always upset you?
176. Are you considered a touchy person?
177. Do people usually misunderstand you?
178. Do you have to be on your guard even with friends?
179. Do you always do things on sudden impulse?
180. Are you easily upset or irritated?
181. Do you go to pieces if you don't constantly control yourself?
182. Do little annoyances get on your nerves and make you angry?
183. Does it make you angry to have anyone tell you what to do?
184. Do people often annoy and irritate you?
185. Do you flare up in anger if you can't have what you want right away?
186. Do you often get into a violent rage?
187. Do you often shake or tremble?
188. Are you constantly keyed up and jittery?
189. Do sudden noises make you jump or shake badly?
190. Do you tremble or feel weak whenever someone shouts at you?
191. Do you become scared at sudden movements or noises at night?
192. Are you often awakened out of your sleep by frightening dreams?
193. Do frightening thoughts keep coming back in your mind?
194. Do you often become suddenly scared for no good reason?
195. Do you often break out in a cold sweat?
196. Have your menstrual periods usually been painful?
197. Have you often felt weak or sick with your periods?
198. Have you often had to lie down when your periods came on?
199. Have you usually been tense or jumpy with your period?
200. Have you ever had constant sever hot flashes and sweats?
201. Have you often been troubled with a vaginal discharge?

Household Record Card

This card provided identification of families and members of each family, allowing space to record each individual's date of birth, sex, employment status, and schooling. It also carried information with regard to environmental data in the home such as sanitary conveniences, heating equipment, type of fuel, etc. (Figure VIII-2).

Individual Sickness Record

A form was selected which asked an answer to the question, "What was the matter?", combined with a check list of symptoms. Space was provided to record information on the severity and duration of each sickness and amount of medical care obtained. Questions were included as to when the person was last seen by a physician, his prepaid health plan coverage, plus a check list to record any pre-existing conditions from which he might suffer (Figure VIII-3). At the end of the first year of the study a preliminary analysis of the sickness data was carried out. This analysis indicated that the individual sickness record did not make adequate allowance for recording exacerbations of a chronic



HOUSEHOLD RECORD CARD DATE:

1. HOUSEHOLD NUMBER ☐☐☐☐ ☐☐☐☐

2. ADDRESS

....
Number and Street

....
City, Town or Village

TELEPHONES: -
Home .... Office ....

3. RACIAL ORIGIN
White ☐ Non White ☐

4. MEMBERS OF HOUSEHOLD				5. RELATION TO HEAD		6. DATE OF BIRTH (Year)	7. SEX	8. EMPLOYMENT AT START OF SURVEY			9. HOW MUCH SCHOOLING	10. INCOME GROUP
									FOR GAINFULLY OCCUPIED ONLY			
Family Number	Indiv. No.	Surname	Given Name	of Household	of Family			(a) Status	(b) Industry (Name of Co.)	(c) Occupation		
	1.											
	2.											
	3.											
	4.											
	5.											
	6.											
	7.											
	8.											
	9.											
	10.											

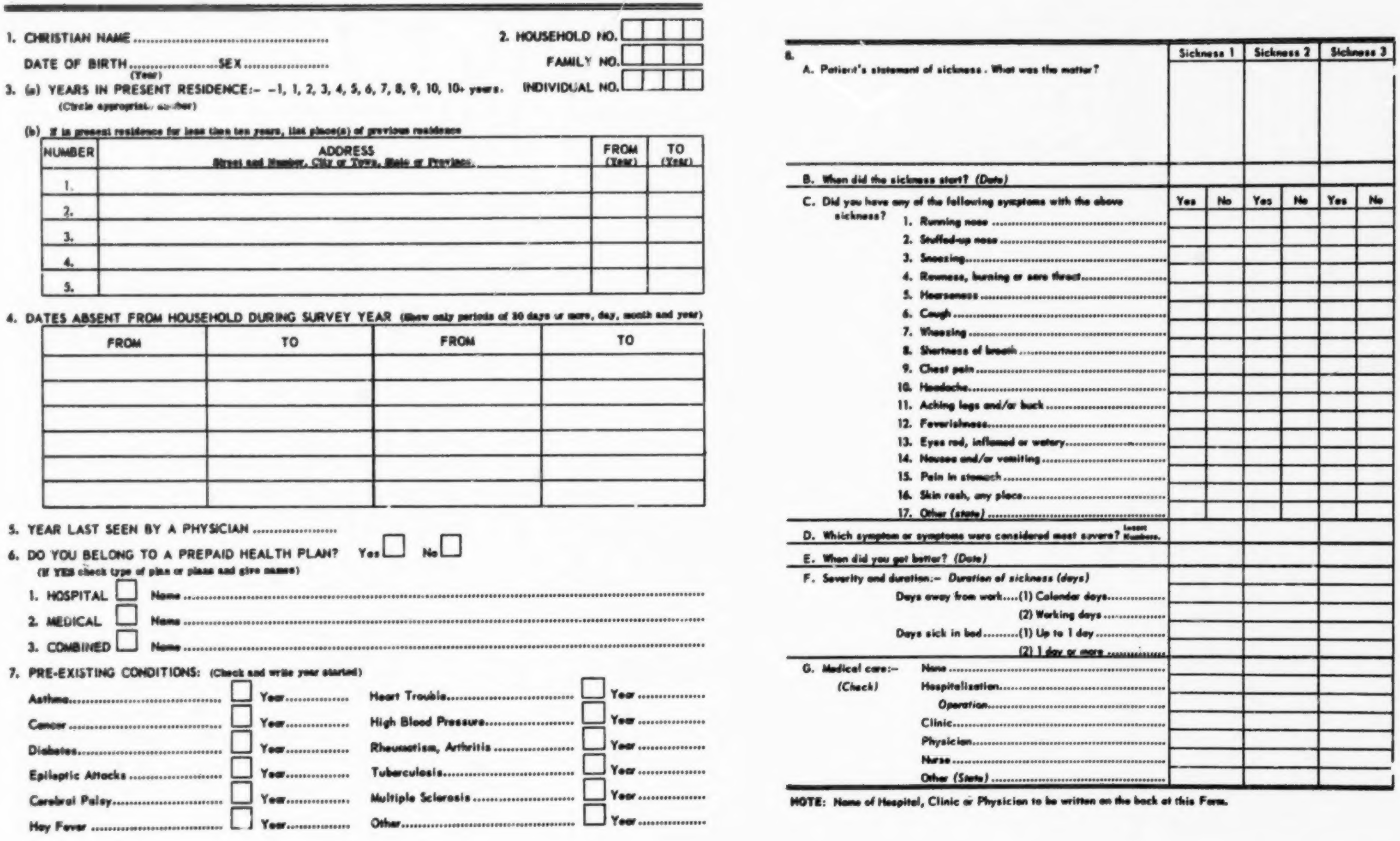
SAMPLE

Office Use Only

1. HOUSING..................Own House.................................. ☐
Tenant.................................. ☐
Monthly Rental........................ ☐
Assessment of Dwelling............. ☐
2. ACCOMMODATION...........Total Rooms Occupied by Household....... ☐
Total Persons in Household.............. ☐
Dwelling in Need of Major Repairs..Yes ☐ No ☐
3. SANITARY CONVENIENCES....Running Water.............................. ☐
(Check if present)
Sewer System.............................. ☐
Septic Tank................................ ☐
Flush Toilet.. .... ☐
Chemical Toilet........................... ☐
Bathtub or Shower......................... ☐
Wash Basin................................. ☐
Kitchen Sink............................... ☐
4. METHOD OF REFRIGERATION..Mechanical.............................. ☐
(Check if present)
Ice Box..................................... ☐
5. HOME ACCESSORIES........Vacuum Cleaner............................ ☐
(Check if present)
Washing Machine........................... ☐
Telephone................................... ☐
Automobile.................................. ☐
6. HEATING EQUIPMENT........Furnace.................................... ☐
(Check if present)
Space Heater............................... ☐
7. TYPE OF FUEL............................Coal ☐ Oil ☐ Gas ☐ Other ☐
(Check)

REMARKS..
....
....

Figure VIII-2. Household Record Card



1. CHRISTIAN NAME .... 2. HOUSEHOLD NO. ☐☐☐☐

DATE OF BIRTH .... SEX .... FAMILY NO. ☐☐☐☐
(Year)

3. (a) YEARS IN PRESENT RESIDENCE:– –1, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+ years. INDIVIDUAL NO. ☐☐☐☐
(Circle appropriate number)

(b) If in present residence for less than ten years, list place(s) of previous residence

NUMBER	ADDRESS Street and Number, City or Town, State or Province.	FROM (Year)	TO (Year)
1.			
2.			
3.			
4.			
5.			

4. DATES ABSENT FROM HOUSEHOLD DURING SURVEY YEAR (Show only periods of 30 days or more, day, month and year)

FROM	TO	FROM	TO

5. YEAR LAST SEEN BY A PHYSICIAN ....

6. DO YOU BELONG TO A PREPAID HEALTH PLAN? Yes ☐ No ☐
(If YES check type of plan or plans and give names)

1. HOSPITAL ☐ Name ....
2. MEDICAL ☐ Name ....
3. COMBINED ☐ Name ....

7. PRE-EXISTING CONDITIONS: (Check and write year started)

Asthma	☐ Year	Heart Trouble	☐ Year ....
Cancer	☐ Year	High Blood Pressure	☐ Year ....
Diabetes	☐ Year	Rheumatism, Arthritis	☐ Year ....
Epileptic Attacks	☐ Year	Tuberculosis	☐ Year ....
Cerebral Palsy	☐ Year	Multiple Sclerosis	☐ Year ....
Hay Fever	☐ Year	Other	☐ Year ....

8.

	Sickness 1		Sickness 2		Sickness 3	
A. Patient's statement of sickness. What was the matter?						
B. When did the sickness start? (Date)						
C. Did you have any of the following symptoms with the above sickness?	Yes	No	Yes	No	Yes	No
1. Running nose						
2. Stuffed-up nose						
3. Sneezing						
4. Rawness, burning or sore throat						
5. Hoarseness						
6. Cough						
7. Wheezing						
8. Shortness of breath						
9. Chest pain						
10. Headache						
11. Aching legs and/or back						
12. Feverishness						
13. Eyes red, inflamed or watery						
14. Nausea and/or vomiting						
15. Pain in stomach						
16. Skin rash, any place						
17. Other (state)						
D. Which symptom or symptoms were considered most severe? Insert Numbers.						
E. When did you get better? (Date)						
F. Severity and duration:– *Duration of sickness (days)*						
Days away from work....(1) Calendar days						
(2) Working days						
Days sick in bed.........(1) Up to 1 day						
(2) 1 day or more						
G. Medical care:– *(Check)* None						
Hospitalization						
Operation						
Clinic						
Physician						
Nurse						
Other (State)						

NOTE: Name of Hospital, Clinic or Physician to be written on the back of this Form.

Figure VIII-3. Individual Sickness Record

illness. In view of this, the record was redesigned (Figure VIII-4).

Sickness Survey Calendar

The form selected was comprised of large squares depicting the days of the month. Into each day's square were written the symptoms and sicknesses of all members of the household on that day. The calendar was to be kept by members of the household and used by enumerators in preparing individual sickness record forms (Figure VIII-5).

Frequency of Enumerator Visits

One visit every two weeks was found most suitable. Weekly visits were too frequent and one visit every three weeks permitted the informants in the household too long a time in which to forget symptoms and dates of sickness.

TRAINING OF ENUMERATORS

Prior to the commencement of the study, all enumerators and supervisors were given a one week training course. The introduction to the course consisted of a description of a number of air pollution disasters, air sampling procedures, and a detailed indoctrination in the purpose of the survey. Intensive instruction was given in the purpose and design of the various questionnaires. Considerable time was spent on methods for recording data as well as on procedure in asking questions. Use of the calendar was explained and techniques were outlined for persuading informants to use it. Written instructions outlining the methods to be used in completing the forms were reviewed and proper interviewing techniques were stressed, especially the method of asking questions which would avoid influencing the answer obtained. Role playing was carried out which afforded the supervisory staff an opportunity to make some evaluation of the results of the training course. As a final check, a written examination was given. Weaknesses revealed by the examination were reviewed with the individual enumerators. A few persons had to be dropped from the staff.

At the end of each six-month period of the study, a thorough refresher course, similar to the initial training course, was given to enumerators. The refresher course dealt with weaknesses that had become apparent during the previous six months.

PUBLIC RELATIONS PROGRAM

From previous experience in field studies of this type, it was known that a carefully planned and executed public relations program would by valuable from both the standpoint of introducing the study to the families and providing stimulation to them throughout its operation.

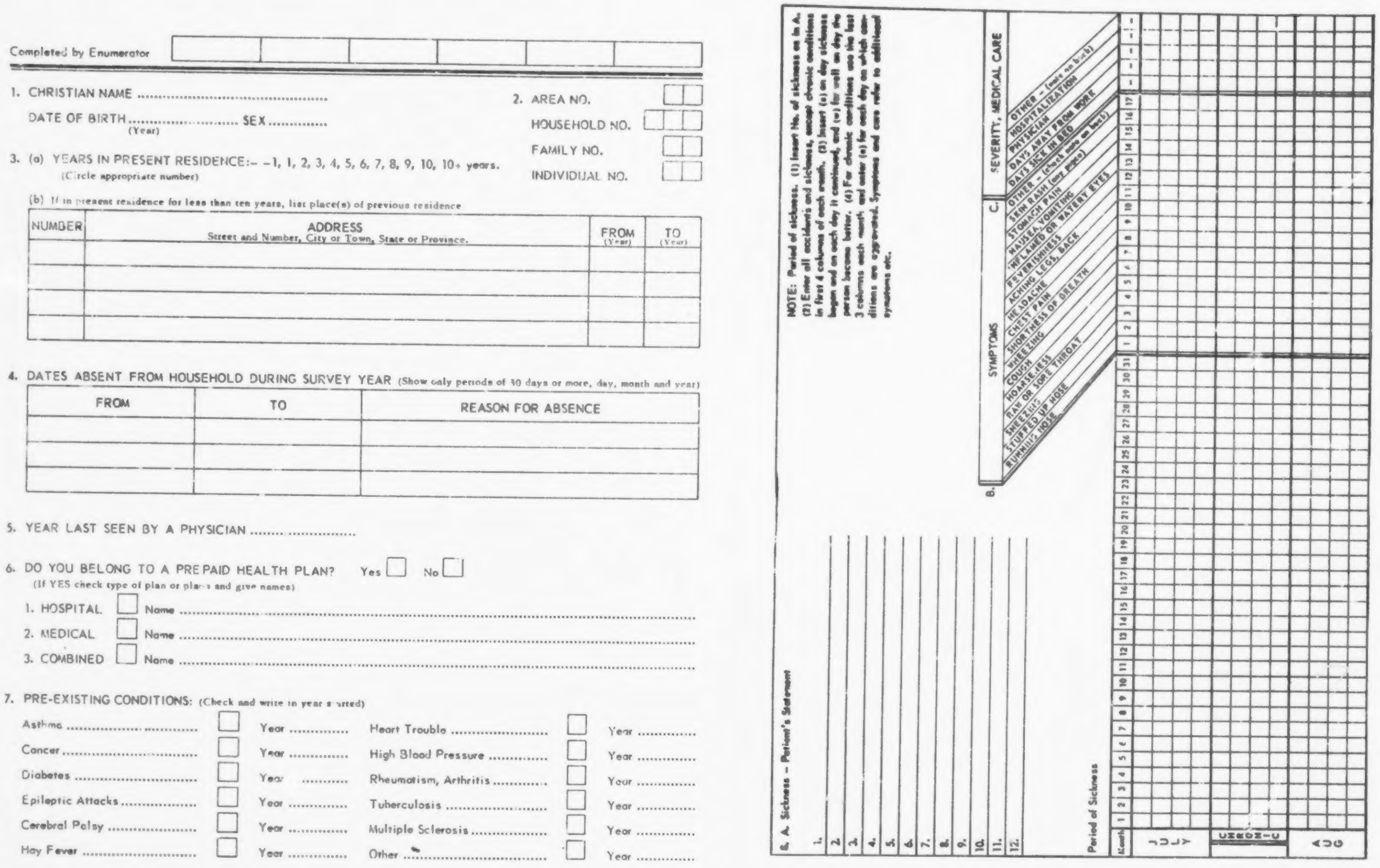
For introductory purposes, a letter was mailed to the householders from the health officers of each area. This letter outlined the desirability of carrying out studies of this nature and gave some insight into their objectives. In addition, three similar letters were sent during the course of the survey. At the conclusion of the field work, a letter of appreciation was sent to the householders thanking them for their cooperation. Christmas cards were mailed and a serious illness was acknowledged with a note of sympathy.

The public relations program was a vital factor in the excellent relationships that developed between families and enumerators. The magnitude of this relationship became apparent during the latter stages of the study when it became necessary to rearrange approximately half of the assignments of families to enumerators. The shift elicited complaints from many householders who did not wish to lose contact with the enumerators whom they had come to know so well. Generally, the reception afforded the enumerators was a most welcome one.

Radio and press releases were issued from time to time. Speeches were delivered to service clubs and other organizations and everything possible was done to ensure that persons involved in the study were aware of the importance of the research.

ADMINISTRATIVE CONTROL OF STUDY

In order to ensure that sickness information was being accurately collected and recorded, a number of controls were instituted. Each enumerator was required to provide a summary sheet every two weeks showing the number of families visited, new sicknesses reported, number of symptoms recorded, etc. (Figure VIII-6). A study of these reports by the supervisory staff resulted in a master compilation outlining the circumstances existing in each of the areas. From this master record, the administrators of the study were able to gain an insight into pro-



Completed by Enumerator ☐☐☐☐☐☐

1. CHRISTIAN NAME ....
DATE OF BIRTH .... SEX ....
(Year)

2. AREA NO. ☐☐
HOUSEHOLD NO. ☐☐☐
FAMILY NO. ☐☐
INDIVIDUAL NO. ☐☐

3. (a) YEARS IN PRESENT RESIDENCE:– –1, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 10+ years.
(Circle appropriate number)

(b) If in present residence for less than ten years, list place(s) of previous residence

NUMBER	ADDRESS Street and Number, City or Town, State or Province.	FROM (Year)	TO (Year)

4. DATES ABSENT FROM HOUSEHOLD DURING SURVEY YEAR (Show only periods of 30 days or more, day, month and year)

FROM	TO	REASON FOR ABSENCE

5. YEAR LAST SEEN BY A PHYSICIAN ....

6. DO YOU BELONG TO A PREPAID HEALTH PLAN? Yes ☐ No ☐
(If YES check type of plan or plans and give names)
1. HOSPITAL ☐ Name ....
2. MEDICAL ☐ Name ....
3. COMBINED ☐ Name ....

7. PRE-EXISTING CONDITIONS: (Check and write in year started)

Asthma	☐	Year	Heart Trouble	☐	Year ....
Cancer	☐	Year	High Blood Pressure	☐	Year ....
Diabetes	☐	Year	Rheumatism, Arthritis	☐	Year ....
Epileptic Attacks	☐	Year	Tuberculosis	☐	Year ....
Cerebral Palsy	☐	Year	Multiple Sclerosis	☐	Year ....
Hay Fever	☐	Year	Other	☐	Year ....

8. A. Sickness – Patient's Statement
1.
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.

NOTE: Period of sickness. (1) Insert No. of sickness as in A. (2) Enter all accidents and sickness, except chronic conditions in first 4 columns of each month. (3) Insert (x) on day sickness began and on each day it continued, and (=) for well on day the person became better. (4) For chronic conditions use the last 3 columns each month and enter (x) for each day on which conditions are aggravated. Symptoms and care refer to additional symptoms etc.

B. SYMPTOMS
RUNNING NOSE
STUFFED UP NOSE
SNEEZING
RAW OR SORE THROAT
HOARSENESS
COUGH
WHEEZING
SHORTNESS OF BREATH
CHEST PAIN
HEADACHE
ACHING LEGS, BACK
FEVERISHNESS
INFLAMED OR WATERY EYES
NAUSEA, VOMITING
STOMACH PAIN
SKIN RASH (any place)
OTHER – (check note on back)

C. SEVERITY, MEDICAL CARE
DAYS SICK IN BED
DAYS AWAY FROM WORK
PHYSICIAN
HOSPITALIZATION
OTHER – (note on back)

Period of Sickness
Month
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
JULY
CHRONIC
AUG

Figure VIII-4. Modified Individual Sickness Record

SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

SAMPLE

DETROIT-WINDSOR AIR POLLUTION INVESTIGATION

This Calendar Will Help You To Keep Track Of Your Family's Illness.

Keep It Handy And Enter Every Illness No Matter How Mild.

HOW TO USE YOUR FAMILY SICKNESS CALENDAR

1. Whenever someone in your family becomes sick, enter on the proper date in the calendar, the name of the sick person and the sickness or complaint.

   EXAMPLE: JOHN -- COLD

   Use the square corresponding to the date the sickness began. Mark down EVERY illness.

2. When the person recovers, put his or her name in the proper square, with the word "BETTER".

   EXAMPLE: JOHN -- BETTER

   Be sure to use the square corresponding to the date the person was better.

We are particularly interested in the following symptoms. Please keep a careful record of them for all sicknesses: --

Running nose
Stuffed-up nose
Sneezing
Sore throat
Hoarseness
Cough

Wheezing
Shortness of breath
Chest pains
Headache
Aching limbs
Feverishness

Inflamed or watery eyes
Nausea and vomiting
Pain in stomach
Skin rash

Figure VIII-5. Sickness Survey Calendar

gress of the field work, e.g., which households were not being visited, in what areas were the number of illnesses abnormally high. Follow-up work with the enumerator concerned ascertained the reasons why families were not visited, why such numbers of sickness reports were collected, etc. Remedial measures were instituted when necessary. The biweekly reports also indicated the approximate number of sickness reports in each area. Comparison of these data with the information collected on pollution levels for the respective areas gave a picture of relationships developing between pollution and sickness levels.

At the end of each six-month period a new individual sickness record was started for each person in the study. This procedure permitted preliminary analysis of the previous six-months' data and also provided a fresh questionnaire for the enumerators to work with. Results of the preliminary analysis, carried out on marginal punch cards, assisted in pointing out many of the shortcomings of enumerators, such as inadequate recording of sicknesses, errors in and omissions from entries on the questionnaire forms, and abnormal numbers of sickness reports collected. The information indicated weaknesses to be covered by the refresher course given to enumerators after each six-month period. Improved records and sounder field techniques resulted.

During each month, field supervisors made complete reviews of all records. At this time, omissions or errors in filling out forms were noted. The enumerators were required to rectify such errors or omissions within a period of two weeks from the time they were noted, even though correction might necessitate revisiting the households. This monthly check ensured that records were kept up to date at all times.

The field supervisors frequently accompanied their enumerators on household visits. Interviewing techniques were observed and weaknesses noted. Comments or suggestions were made to the enumerators after departing from the household. These visits acquainted the administrative staff with the response of the householders, sharpened the enumerators' techniques, and stimulated interest and enthusiasm in their work.

In the Canadian areas, duplicate enumeration was conducted during the last month of the study to obtain an idea of the information, if any, overlooked by enumerators. Three persons were selected for this work, the field director of the study and two statisticians who had been connected with the survey for some time. They revisited a number of households in each area and recorded all sicknesses that had occurred during the previous month, collected information on the amount of medical and hospital care received, and recorded chronic conditions suffered. These data were then compared with the original information gathered by the enumerators for the same persons over the same period. Agreement between results of the two enumerations was found to be satisfactory.

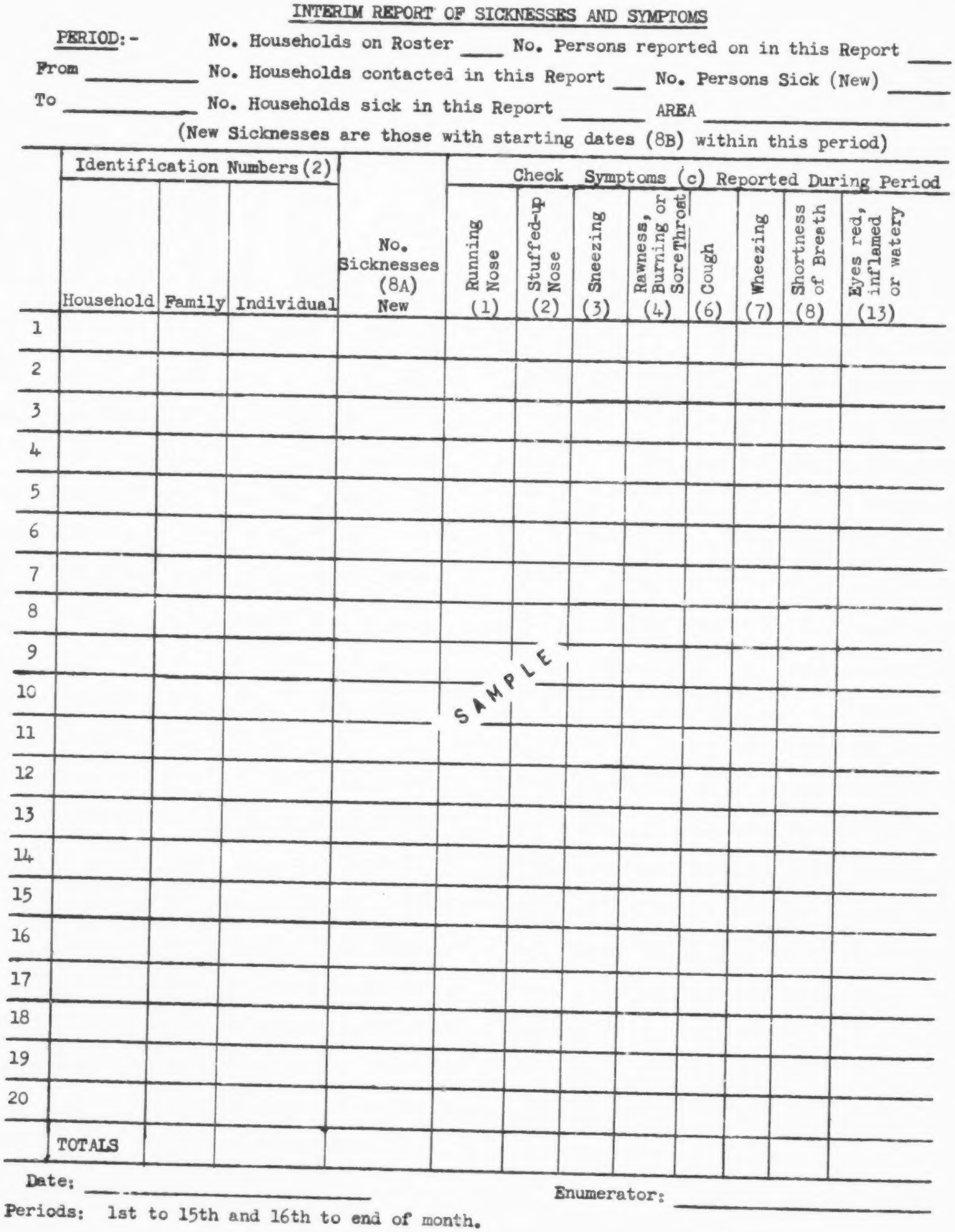
During the last six months of the study, half of the families of each Windsor-area enumerator were interchanged to reduce or eliminate enumerator bias that could have developed over the previous eighteen months. The interchange also allowed comparisons which provided a further check on data validity.

As previously stated, two highly skilled interviewers, female social workers with extensive background in case-work interviews, were employed during the last three months of the study. They were assigned to interview a few families taken from other enumerators. The data they collected were compared with the data collected by the regular enumerators. This comparison indicated little difference between the quality of data collected by the two types of enumerators.

HOUSEHOLD PARTICIPATION

Most of the households contacted were willing to participate in the survey. Of the households asked to participate, 88 percent in some areas to 99 percent in others agreed to do so. Of the original households participating at the beginning of the study, 90 to 99 percent were participating at the end of six months (the range being variation from one area to another), 77 to 92 percent were participating at the end of one year and 7[illegible] to 80 percent at the end of eighteen months.

Replacement households taken from reserve lists, established before the study began, and new occupants of dwellings formerly occupied by participants (when the new occupants agreed to participate) would have no important effect on the randomness of the households. However, a small number of households were used as replacements because of their requests to partici-



INTERIM REPORT OF SICKNESSES AND SYMPTOMS

PERIOD:- No. Households on Roster ____ No. Persons reported on in this Report ____
From __________ No. Households contacted in this Report ___ No. Persons Sick (New) _____
To ___________ No. Households sick in this Report _______ AREA ____________________
(New Sicknesses are those with starting dates (8B) within this period)

	Identification Numbers (2)				Check Symptoms (c) Reported During Period							
	Household	Family	Individual	No. Sicknesses (8A) New	Running Nose (1)	Stuffed-up Nose (2)	Sneezing (3)	Rawness, Burning or Sore Throat (4)	Cough (6)	Wheezing (7)	Shortness of Breath (8)	Eyes red, inflamed or watery (13)
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												
	TOTALS											

SAMPLE

Date: ____________________ Enumerator: ____________________
Periods: 1st to 15th and 16th to end of month.

Figure VIII-6. Interim Report of Sickness and Symptoms

pate or because another participant asked that they be included. These changes may have had a slight effect on the randomness of the households.

The number of persons living in Kingsville and Harrow was small. There is a possibility that by the third six-month period of the study, those participating represented the majority of households willing to participate rather than a proper sampling of the population. On the other hand, the age distribution of people participating in the study for all areas appeared to be more consistent during the third six-month period than at the beginning of the study, tending to indicate that the persons participating represented a valid sample of the population for the purposes of the study

FINDINGS AND CONCLUSIONS

Measurements of pollution in the health study areas during the period of its conduct and subsequent to its completion demonstrated that the difference in pollution levels between high and low pollution areas was not very great. This fact contributed to difficulties encountered in interpretation of data gathered in the health study.

With regard to the two areas of white population in Detroit, suspended particulate matter was found to average about 1.8 times greater in the high pollution area than in the low with an average difference of about 100 micrograms per cubic meter. Sulfur dioxide concentrations were about twice as great in the high pollution area as in the low pollution area with a difference in averages of about 0.05 p.p.m. These two stations were most unlike of all of the pairs of areas in the study.

In the two areas of nonwhite population in Detroit, suspended particulate matter was found to average only about 1.3 times greater in the high pollution area than in the low pollution area. The difference between the two was about 35 micrograms per cubic meter. Sulfur dioxide concentrations in the high pollution area were about double those found in the low pollution area with a difference in averages of about 0.05 p.p.m.

In the two Windsor areas, average suspended particulate matter concentrations in the high pollution area were about 1.2 times those in the low pollution area. The difference between the two was about 20 micrograms per cubic meter. Sulfur dioxide concentrations in the high pollution area averaged about 0.03 p.p.m. above those in the low pollution area.

The air over the control area in Harrow was found to be less polluted than all other areas in Windsor and Detroit. Suspended particulate matter concentrations in the high pollution area in Windsor averaged about 2.2 times those in Harrow. Sulfur dioxide concentrations in the high pollution area in Windsor averaged about 0.03 p.p.m. above those in Harrow.

Generally speaking, pollution levels in all the health study areas followed a similar chronological pattern. When pollution was relatively high in one area, it was also relatively high in the others. It was noted, however, that in many instances when pollution levels in the low pollution areas were relatively high, they were above those found on some days in the high pollution areas.

There is conjecture as to whether the percentage or absolute differences in pollution levels in the high and low pollution areas were sufficient to cause recognizable differences in the reactions of people living in the different areas. There is also doubt as to whether the pollution levels in the areas had reached the threshold where the people react to the pollution by developing conditions detectable in a day to day morbidity study.

Analysis of the replies to the Cornell Medical Index questionnaire indicated that people in the two high pollution areas in Detroit reported themselves afflicted with more symptoms of illness than people living in the two low pollution areas. This was particularly true. and apparently statistically significant in regard to prevalence of coughing, colds, headaches, and pains in the arms and legs. This, of course, does not prove that higher air pollution levels caused the greater reported incidence of the symptoms, but it is interesting that the two vary directly. In answer to only one question, "Do sudden noises make you jump or shake badly?" did the people in the high pollution areas in Detroit report a statistically significant lower incidence than people in the low pollution areas.

In the assessment of sickness experience and health status of the people under study, a variety of indices could have been used. Those selected were intended to present the morbidity picture in a way to give optimum sensitivity(88). A summary of morbidity experience is given in Table VIII-3. Assessment of health experience in the areas in terms of the measurements used of the incidence, prevalence, and duration of sickness did not reveal any consistent differences between high and low pollution areas. Levels of sickness were not found to be lower in the control areas where pollution concentrations are minimal. The sickness level appears to be higher in the control areas and is exceeded (apparently) only in the high and part of the time low pollution areas of white population in Detroit. A separate examination of data from the two control areas revealed that differences between these areas were generally greater than between the Windsor high and low pollution areas(88). One interesting fact is that case incidence rates in the Detroit low pollution area of white population were remarkably below those in the Detroit high pollution area of white population.

Statistical studies were made of the data using various groupings in an effort to find greater meaning. Factors used included type of sickness, age, number of times sickness began, number of days of sickness, pre-existing physical conditions, persons sick on the first day of a period, and persons becoming sick during a period. Extensive statistical work failed to reveal indications of significant differences in these various factors among the populations living under existing conditions of atmospheric pollution.

The monthly rate of sickness in all areas followed a similar chronological pattern, although at differing levels. The two areas populated by nonwhite poeple in Detroit evidenced this tendency to the least degree. One remarkable finding arose from the accumulated data. This was the striking pattern of sickness rates in the two Detroit areas populated by white people. The sickness rates in the high pollution area were

Table VIII-3. Comparative Morbidity by Study Area(88, 93)

Morbidity index and period	Health Study Areas							
	Detroit				Windsor		Kingsville	Harrow
	White Population		Nonwhite Population					
	High pollution	Low pollution	High pollution	Low pollution	High pollution	Low pollution	Control	Control
Maximum case incidence (Rate per 100 persons observed)								
July-Dec. 1953	338	272	154	143	160	156	161	205
Jan.-June 1954	194	185	113	118	144	154	155	161
July-Dec. 1954	242	178	74	85	170	192	167	254
Person incidence - percent (Rate per 100 persons observed)								
July-Dec. 1953	83	84	68	62	68	66	64	80
Jan.-June 1954	73	69	60	59	73	72	67	75
July-Dec. 1954	48	65	44	45	73	74	72	82
Median duration of sickness (Days/person)								
July-Dec. 1953	4	4	9	6	7	6	8	15
Jan.-June 1954	7	5	7	6	8	8	8	14
July-Dec. 1954	18	19	7	8	10	10	9	18
Proportion of time lost - percent (Days sick/days exposure)								
July-Dec. 1953	19	13	10	10	9	8	12	14
Jan.-June 1954	14	13	6	7	9	8	12	16
July-Dec. 1954	10	10	4	4	9	10	10	15

Adapted from references

generally above those in the low pollution area and both followed a similar pattern (Figure VIII-7). This pattern failed to appear as clearly when comparing the two nonwhite populated areas in Detroit and the two areas in Windsor. One possible explanation is the fact that pollution level differences between the two white populated areas in Detroit were greater than differences in the other two pairs.

This study was intended primarily as a pilot project, to investigate the potentialities of the household morbidity survey as an instrument for measuring health in relation to pollution. The investigation clearly emphasizes the need for further consideration of the best approaches to elucidation of the relationship, if any, between air contamination and the health status and sickness experience of the exposed populations.

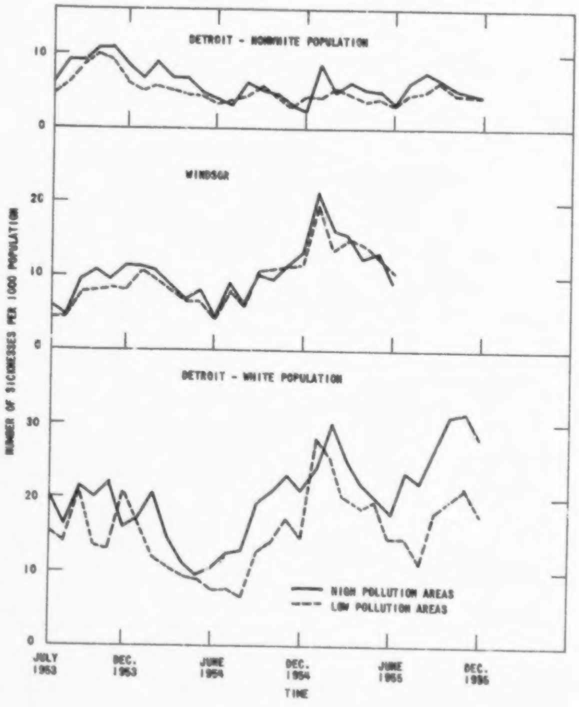


Figure VIII-7. Average Daily Rate of Sickness

OTHER STUDIES

RESPIRATORY CANCER MORTALITY

Deaths attributed to cancer of the respiratory tract in Detroit during the period 1946 to 1949 were collected and analyzed. Figure VIII-8 shows age-specific respiratory tract cancer rates in areas of high and low atmospheric pollution. With respect to sex, there is a higher rate for males than for females and, for both sexes, there is a higher rate in areas of high pollution than in areas of low pollution. An analysis of these data shows the difference to be statistically significant.

MORTALITY DURING A SMOG EPISODE

During the early part of September 1952, a three-day period of atmospheric stagnation occurred in the Detroit-Windsor area. Meteorological conditions were such that pollution levels reached unusually high values. There were many complaints of eye irritation and respiratory discomfort by citizens. A study of mortality records for the area revealed a striking rise in infant mortality and in deaths of individuals with malignant disease during the period. (Figure VIII-9) This relationship of mortality in vulnerable groups to rises in atmospheric pollution has been demonstrated several times in other areas. The dramatic rises in mortality in the London smog of 1952 have aroused great interest throughout the world. The fact that a similar phenomenon was demonstrable in the Detroit-Windsor area is worthy of note.

OTHERS

In further effort to evaluate the possible relation between air pollution and health, a number of additional sources of data were examined. Studies were conducted as follows:

1. "Review of Windsor Medical Care Plan Records"
2. "Survey of Chronic Respiratory Diseases Treated by Doctors"
3. "Study of Nasal Preparation Sales"
4. "Review of Elementary School Absenteeism"
5. "Comparison of Morbidity and Mortality Data"

These five investigations are not described in this report because the findings in each case were inconclusive.

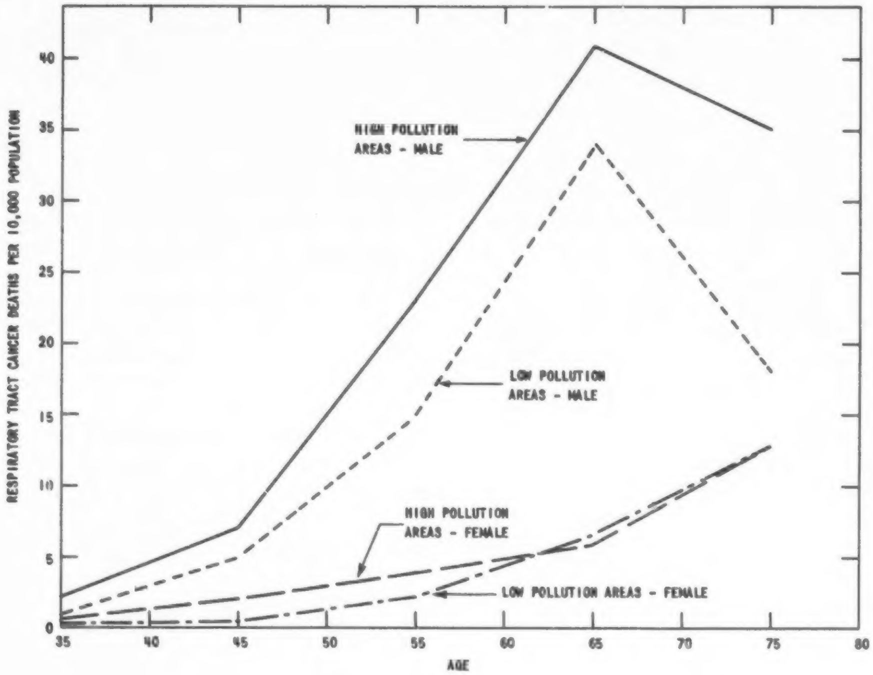


Figure VIII-8. Respiratory Tract Cancer Mortality; Detroit, 1946 to 1949

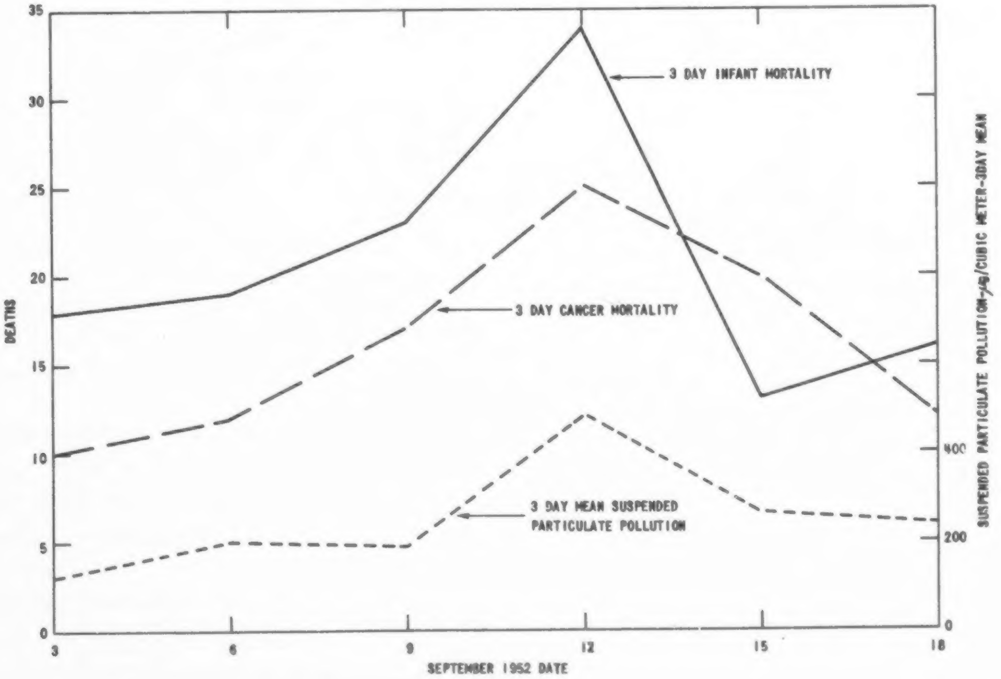


Figure VIII-9. Infant and Cancer Mortality in Detroit - Windsor During a Smog Episode

Chapter IX

EFFECTS OF POLLUTION ON VEGETATION

INTRODUCTION

Industrial expansion in the Detroit-Windsor study area since World War II has not increased the general density of plants in the area but rather has extended the boundaries into areas which were until recently rural. As a part or consequence of this pattern of development and growth, vegetation within the area is widespread and varied.

In such an urban area, abnormalities in leaves, in vegetative growth, or in the general unthrifty appearance of vegetation are frequently ascribed to air pollution, often without sound evidence. Unfortunately, the literature on the effects of air pollution on vegetation is far from adequate. Prime consideration has generally been given to specific instances of acute emission of a single noxious material. Generally, the effects have been expressed subjectively rather than quantitatively.

The most obvious and dramatic symptoms of air pollution injury to vegetation consists of dead and necrotic areas in the foliage. These symptoms may manifest as marginal burn, leaftip burn or die-back, or as necrotic interveinal areas. Different species of plants vary widely in susceptibility to injury by atmospheric pollutants. Varietal differences are also recognized. In some cases the pattern of foliar injury and the species involved or not involved will indicate a specific pollutant and may indicate the degree of fumigation received.

While the injury symptoms for certain pollutants on specific varieties may appear characteristic, they are not specific. Disease, insect injury, cultural malpractice, singly or in combination, may produce a similar if not identical syndrome. In the case of the nonspecific complaint of poor growth, especially in highly urbanized areas, considerable caution must be exercised. Inadequate water, poor drainage, restricted root space, soil compaction, nutritional imbalances, and soil contamination from street surfaces all may contribute to poor growth.

Given only a set of visible symptoms of foliar injury, it will probably never be possible to deduce with a satisfactory degree of confidence, the nature and amount of exposure to an injurious pollutant. A guess may sometimes be ventured, but always subject to uncertainties arising from the age of the tissue, site conditions, and prevailing weather conditions. When the visible symptoms are later supported by chemical analysis, the interpretation is less equivocal. For example, in the Trail Smelter area, the single source of a definite suspect pollutant, with comparable vegetation over a wide area, permitted correlation of the observed foliar injury with sulfate levels in the plant and sulfur dioxide levels in the air, resulting in a rather uncomprised relation.

ORGANIZATION AND PLAN OF VEGETATION STUDY

The survey team consisted of representatives of various organizations of the cities of Detroit, Windsor, and Wyandotte, Wayne County, the State of Michigan, and the Canadian Government.

The basic plan of the study as initally conceived was twofold:

1. Periodic tours through the area by the survey team would give a general, if subjective, picture of the over-all pattern;

2. Use of specific indicator plants at selected locations under controlled cultural conditions should give at least a quantitative measure of response to the air pollution levels in these selected areas.

For the second part of this program to succeed, the plants had to receive consistent, uniform, and good care. Provision had to be made to replace the plants periodically in order to expose at all times plant tissues of the proper age for most characteristic and specific response. Since no assurances could be given for the proper care and protection necessary for valid use of the plants, this phase of the plan was not implemented.

Accordingly, the survey team made general surveys of vegetation throughout the study area and particularly in the vicinity of probable sources of pollutants, in an attempt to determine the susceptibility of the species and the nature and extent of injury. The survey was aided by the fact that in the Detroit area small garden plots are to be found in almost every street and in the immediate vicinity of almost all heavy industrial installations. This circumstance is of great value in a survey of this type because, in general, the same species with more or less comparable age are to be found in these garden plots.

In 1953, four surveys were made approximately biweekly beginning in the middle of June. In 1954, eleven weekly surveys were made from May 5 to August 4. The inspection teams systematically sought areas of expected high pollution and made repeated visits to those areas that appeared to contain injured species.

FINDINGS

In general, the appearance of herbaceous species, annual and perennial, was normal or as near normal as the general cultural conditions of the site might be expected to allow. This was an area-wide observation. While there were specific areas within the region of suspected sources in which injury or poor growth could possibly be attributed to air pollution, there was no indication of a general repression of growth, or of insipiency of foliar injury over extensive areas.

Where symptoms of injury to vegetation, presumably attributable to air pollution, were found, they were limited generally to a few susceptible species in the immediate vicinity of a probable source of the pollutant. Careful examination of the plants usually suggested that the injury arose from a specific incident or combination of circumstances of relatively short duration rather than from long-term chronic exposure.

The least equivocal evidence of air pollution injury could be found more frequently in May and early June than later in the season. By August the normal senescence, perhaps in some instances accelerated by poor cultural care, made it impossible to distinguish between suspected pollution injury and other effects. The plantain lily, Hosta plantaginea, appeared to be a good indicator in May and June. However, not all varieties are equally sensitive. Also such spring bulbous plants as tulips and lilies-of-the-valley seemed to be good indicators. Since these plants have no summer growth potential, the pattern of injury changed little as the season progressed.

Several times the team visited an area contingent to a plant from which known emissions of chlorine had occurred at intervals. Virtually all vegetation 50 to 100 yards from the source was affected to some degree, whole 500 to 600 yards downwind from the source little or no injury was observed. The symptoms of injury varied greatly. On some, leaves were partially bleached; some became translucent; some showed marginal burn with cupping, and with some plants there was moderate to extensive defoliation, often without much damage to the leaf lamina. Interestingly, Hosta, which is sensitive to sulfur dioxide, was not injured by chlorine while ailanthus, which appears insensitive to general urban pollution, was extensively defoliated by chlorine. While these observations are of interest from the standpoint of the response of vegetation to the massive dosage of chlorine that must have occurred, they cannot be said to apply to the broad problem of subacute air pollution. These emissions, damaging to vegetation and property, can be tolerated only as calamitous accidents.

The study of the woody species presented many difficulties in evaluating cause and effect. In all areas trees were found which appeared normal and, conversely in nonpolluted areas, trees and shrubs were found which appeared unhealthy or abnormal in some respect. General cultural conditions appear to override and obscure any environmental effect of air pollution.

The Canadian section took samples, especially of conifers, for analysis of sulfur content and of the change of chlorophill to pheophytin, as possible indication of the effect of acid gases, especially SO_2(110).

The results of the sulfur analyses on the vegetation samples are approximately consistent with the known distribution of sulfur dioxide contamination in the Detroit River area. The data in regard to the chlorophyll conversion to pheophytin are inconclusive. While the percentage conversion seems to indicate a correlation with the visible abnormality in the vegetation, the relation to air pollution is not established. Further work along these and similar lines may prove fruitful.

Chapter X

OTHER EFFECTS OF POLLUTION

INTRODUCTION

Information is very meager concerning the effects of air pollution on visibility and safety, on the deterioration of materials, and economic losses due to air pollution. With the exception of a limited study of the relationship between visibility and air pollution (Chapter XI) the Technical Advisory Board conducted no studies of these facets of the air pollution problem.

The adverse effects on property through deposition of smoke particles and fly ash, the action of acid gases, and the soiling of surfaces by aerosol pollutants represent economic losses. These losses include damage to fabrics, household equipment, merchandise, buildings, metal products, and other exposed materials. It is difficult to place an exact value on the total economic losses resulting from contaminated air because of their varied nature and the lack of an organized procedure for accumulating proper statistics. However, from published data it is possible to obtain an approximation of these effects in the Detroit-Windsor area.

VISIBILITY AND SAFETY

The tremendous numbers of minute liquid and solid particles emitted into the atmosphere as dust, smoke, or fumes, absorb, reflect or refract light and thereby obscure objects from vision. Results of a survey in Los Angeles(48) indicated that carbon and metallic particles were responsible for 10 to 50 percent of the decrease in visibility. Water-insoluble particles, including aluminum oxides and silica, accounted for 10 to 30 percent of the decrease; substances capable of forming moisture droplets in the air, principally sulfur trioxide, accounted for 5 to 20 percent of the decrease; and large soluble crystals, as sulfates, nitrates, and chlorides, accounted for as much as 80 percent.

When the concentration of certain sizes of aerosols in the atmosphere reaches high levels, loss in visibility may restrict airport operations. Aircraft may have to operate on instruments and fileds may have to be closed. In a recent study at the Newark, New Jersey, airport(98) it was found that visibility was restricted nearly half of the time because of smoke. If airports are to be used to their greatest capacity, visibility must be such that traffic can move in and out safely and quickly.

Reduction in visibility due to air pollutants may create a serious hazard to automobile traffic. Reports of accidents, lives lost, and property damage attributable to restricted vision produced by air pollutants are lacking. However, continual reduced visibilities as observed on the streets and expressways of many metropolitan areas indicate that hazards exist. An air pollution investigation(76) in London in 1954 showed that visibility in certain areas was reduced to 200 yards for a few hours on several occasions. On one day the visibility was reduced to 70 yards. These records were made in the absence of fog and the visibility reductions are presumed to be due solely to man-made pollutants.

In addition to hazards caused by reduced visibility, there is the possibility that air over city streets contains sufficient amounts of pollutants (particularly carbon monoxide) to cause a reduction in the efficiency and alertness of vehicle operators and pedestrians and thus increase the possibility of accidents. No specific data are yet available on this aspect of the problem but the likelihood that such a situation exists was considered sufficiently possible that personnel from the University of Michigan (in cooperation with others) are presently conducting a sizable study of the matter in Detroit.

DETERIORATION OF MATERIALS

DETERIORATION MECHANISMS

Corrosive agents can be placed in four major categories:(26)

1. Oxygen and oxidants including ozone, nitric oxides and nitrous acid, and organic peroxides.

2. Acidic materials including sulfur dioxide and sulfurous acid, sulfuric acid, hydrogen sulfide, hydrochloric acid, carbon dioxide and carbonic acid, and tar acids.

3. Salts, including ammonium sulfate and other ammonium salts, and sodium chloride.

4. Alkalies.

All of the above may exist in polluted atmospheres of metropolitan areas.

Free oxygen in the atmosphere causes corrosion when it is dissolved in a thin film of liquid on a metallic surface. A slow chemical and electrochemical reaction is set up which results in deterioration of the metal. There are many materials relatively resistant to the attack of free oxygen, although these same materials may be less resistant to the action of peroxides and such oxidants as nitric oxide and nitric acid. These, like free oxygen, are absorbed by the liquid surface film. The resulting chemical action converts the metal to its oxide, which readily dissolves when acted upon by acids present in the polluted air. Thus, there is a gradual dissolution of the metal attacked.

The acid gases which play a significant part in corrosion are given off during combustion and other processes in every city. In the majority of metropolitan areas, the most important of these gases is sulfur dioxide. Investigations have repeatedly demonstrated that the total acidity of community atmospheres is closely related to the sulfur dioxide content. In comparison, such acidic materials as sulfuric acid, hydrogen sulfide, hydrochloric acid, and nitric acid are usually of relatively minor importance.

Coal, gas, and petroleum fuels contain varying amounts of sulfur. When these fuels are burned, most of the sulfur passes to the atmosphere as sulfur dioxide or sulfur trioxide, the latter forming sulfuric acid upon contact with moisture in the air. The acid thus formed may be washed from the atmosphere by rain, removed from the air upon being absorbed or adsorbed by dust or soot, or become attached to surfaces. Thus, exposed materials are subjected to acid rains, to sulfur compounds which leach from dust or soot stuck on their surfaces, and by direct contact with aerosols of acid.

The effect of tar and tar acids (resulting largely from combustion of fuels) should not be overlooked. These are sticky and cling to surfaces, enabling the acids which the tar contains to attack the material over a prolonged period of time(26).

Salts, such as ammonium sulfate and sodium chloride, are very corrosive. They are most abundant in marine atmosphere. However, they also exist in man-polluted atmospheres since sulfuric acid aerosols readily combine with ammonia to form ammonium sulfate, and hydrochloric acid aerosols react with ammonia to form ammonium chloride. These salts hydrolyze in water to form sulfuric and hydrochloric acid, which have marked corrosive action.

Alkalies are among the less common pollutants of urban and industrial atmospheres. However, these too, are corrosive and must be considered in corrosion problems.

CORROSION OF METALS

Corrosion of metals caused by air pollutants is generally considered a serious problem. Articles commonly attacked by air pollutants include autos and trucks, tools, gutters, window screens, metal flashings, rails, electric utility power transmission facilities and structural and ornamental building components. That industrial atmospheres accelerate the process of metallic corrosion has been demonstrated by several investigators. Table X-1 indicates that iron corrodes about three times more in industrial areas than in rural areas. This does not mean that only industrial emissions cause the more rapid corrosion but that the net effect of pollutants from all sources in the community cause the more rapid deterioration. The relative corrosiveness of other types of atmospheres is also indicated(44). Table X-2 indicates the relative corrosiveness of industrial, seacoast and rural atmospheres with respect to several nonferrous metals. It is indicated that the metals deteriorate 2 to 20 times more in industrial atmospheres than in rural atmospheres(85). Figure X-1 shows graphically the great differences in amount of corrosion of nickel in various atmospheres (85). Surveys made in Springfield, Illinois(107) showed that the corrosion rate on clean steel surfaces in that city were as much as thirty

Table X-1. Relative Corrodibility of Atmospheres at Twenty Locations Throughout the World(44)

(Losses of weight of 5.1 by 10.2 centimeter specimens of open hearth iron containing 0.07 percent copper used as criteria)

Location	Type of Atmosphere	Mean Losses of Weight, grams	Relative Corrodibility[a]	Number of Tests
Khartoum, Egypt	Dry Inland	0.16	1	9
Abisco, North Sweden	Unpolluted	0.46	3	6
Aro, Nigeria	Tropical Inland	1.19	8	7
Singapore, Malaya	Tropical Marine	1.36	9	10
Basrah, Iran	Dry Inland	1.39	9	8
Apapa, Nigeria	Tropical Marine	2.29	15	7
State College, Pennsylvania	Rural	3.75	25	1
South Bend, Pennsylvania	Semi-Rural	4.27	29	1
Berlin, Germany	Semi-Industrial	4.71	32	3
Llanwrtyd Wells, British Isles	Semi-Marine	5.23	35	11
Kure Beach, North Carolina	Marine	5.78	38	1
Calshot, British Isles	Marine	6.10	41	10
Sandy Hook, New Jersey	Marine, Semi-Industrial	7.34	50	9
Congella, South Africa	Marine	7.34	50	9
Kearny, New Jersey	Industrial-Marine	7.75	52	1
Motherwell, British Isles	Industrial	8.17	55	10
Vandergrift, Pennsylvania	Industrial	8.34	56	1
Pittsburgh, Pennsylvania	Industrial	9.65	65	1
Sheffield, British Isles	Industrial	11.53	78	9
Frodingham, British Isles	Industrial	14.81	100	6

[a] Frodingham = 100.

Table X-2. Weight Loss of Non-Ferrous Metals in Various Atmospheres(85)

(About 1930 to 1954)

City	Exposure Classification	Average Loss in Weight - Percent					
		Comm. Copper 99.9% + Cu	Comm. Aluminum 99% + Al	Brass 85% Cu 15% Zn	Nickel 99% + Ni	Comm. Lead 99.92% Pb 0.06% Cu	Comm. Zinc 99% Zn 0.85% Pb
Altoona, Pa.	Industrial	6.1	---	8.5	25.2	1.8	30.7
New York, N. Y.	Industrial	6.4	3.4	8.7	16.6	---	25.1
La Jolla, Cal.	Seacoast	5.4	2.6	1.3	0.6	2.1	6.9
Key West, Fla.	Seacoast	2.4	---	2.5	0.5	---	2.9
State College, Pa.	Rural	1.9	0.4	2.0	1.0	1.4	5.0
Phoenix, Ariz.	Rural	0.6	0.3	0.5	0.2	0.4	0.8

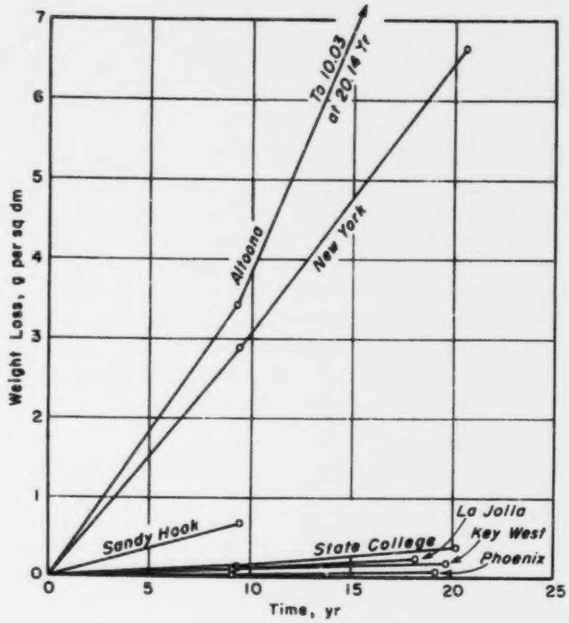


Figure X-1. Weight - Loss Time Curves for Nickel (99% +) in ASTM Tests

times that in rural areas. Another investigation(87) suggested that in England about one-third of the annual replacement of steel rails is required because of corrosion due to air pollution. Other evidence gives replacement rates of steel in existing structures as 0.5 percent each year as the consequence of pollution(87).

No data directly applicable to the Detroit-Windsor area relative to corrosion rates were obtained. However, knowledge of pollution levels in the area and of those probably existing in other areas where corrosion rates were measured, leaves no doubt that corrosion of metals due to atmospheric pollution is an important problem in the Detroit-Windsor area.

DETERIORATION OF OTHER MATERIALS

Building stones composed largely of limestone tend to have their insoluble carbonates converted to soluble sulfates or chlorides by acidic rainwater. This conversion causes a swelling of the stone and the surface flakes off. If the stone is a magnesium limestone, soluble magnesium sulfate may be formed and washed away by rain, causing slow but eventual, complete disintegration. Sandstone may be deteriorated in the same manner though ordinarily to a lesser degree.

Other materials damaged by atmospheric pollutants include textiles, leather, rubber, and paper. Perhaps the most recent example of damage to textiles is the spontaneous runs which occurred in nylon hosiery worn by women on the streets of Jacksonville, Florida. A suspected cause was the adherence to the stocking of droplets of sulfuric acid, or acid impregnated soot. The most probable source of the acid in this case was from automobile exhaust(26).

Leather-bound books and leather chairs have been reported to be attacked by air pollutants, especially sulfur dioxide. There is evidence that vegetable-tanned leather rapidly absorbs sulfur dioxide. Analyses made of book bindings in London showed concentrations of sulfuric acid up to five percent.

Rubber is subject to severe damage by air pollutants. The significant pollutant in this case is ozone which causes cracking. Accelerated deterioration of automotive tires and of rubber used in telephone installations are examples of such damage.

Sulfur dioxide has been found to affect paper to a high degree(8). Controlled exposures of paper to this gas have resulted in embrittlement and decreased folding endurance.

ECONOMIC LOSSES

People living in the United States lose billions of dollars every year because of air pollution. The pollutants which society pours into the air every day damage almost everything they touch. Metal work is corroded, buildings are defaced, paints are discolored or destroyed. Clothing is soiled while being worn; laundry hanging on clotheslines is soiled before it dries; curtains, wallpaper, and draperies are ruined before their time; automobiles are covered with soot and dust. Pollutants damage or ruin merchandise in stores before it can be sold. They obscure the sun and necessitate the use of artificial light. Every person is oblidged to spend more money for extra laundry, cleaning, painting, replacements and redecorating.

The full economic effect of air pollution is difficult, if not impossible, to assess. In making estimates, investigators have confined themselves to those items which are measurable in terms of money. Hence, regardless of how consequential they may be, no account is taken of such items as the effect of air pollution on health, lessened efficiency, absenteeism, or loss of citizens who move to the suburbs. However, when the complexity of making precise estimates is realized and the inevitable wide limits among published statistics are understood, the dollar values of the measurable costs can indicate, to some degree, the magnitude of air pollution economic losses.

A number of attempts to determine the costs of air pollution per person have been made. One estimate indicated that smoke in and around American cities costs each inhabitant of those areas $17.00 annually(21). The National Conference on Sanitation of New York City indicated that an annual loss of $16.00 per person is attributable to air pollution damage to fabrics, household equipment, and buildings(21). At least three independent estimates place the loss in the City of Chicago at about $20.00 per person per year(21). The annual cost for Milwaukee has been reported as $17.00 per capita; and for Indianapolis, $14.00 per capita(74). In Great Britain the cost per person per year is estimated to vary from $15.00 for the overall population to at least $30.00 for those living in areas of very high pollution(96). Some years ago the United States Department of Commerce estimated that the cost of damage from smoke in various cities amounts to $8.00 to $20.00 per person per year(21).

With regard to the Detroit-Windsor area, bearing in mind the levels of dustfall, air-borne particulate matter, sulfur dioxide, and other contaminants, it is reasonable to estimate that economic losses from air pollution are at least $20.00 per capita per year. For the approximately 3,500,000 inhabitants of the Detroit-Windsor area, this annual loss totals approximately $70,000,000.

Other estimates state economic losses for an entire community(21). One investigator announced the cost to the people of Chicago for excessive laundry bills; damage to fabrics, buildings, and metal products; and loss of heating efficiency, to be in excess of $50,000,000 per year. Other estimates on smoke damage place Pittsburgh's annual loss at $10,000,000, Cincinnati's at $8,000,000, and Cleveland's at $6,000,000. The national loss has been set at approximately 1.5 billion dollars per year, or about $10.00 for every person living in the United States(21).

Results of a survey in 1951 of the annual loss due to air pollution to department stores, hospitals, hotels, and large office buildings in 15 of the largest cities in the nation have been reported(21). Twenty large department stores estimated annual losses of $20,000 to $50,000 each; ten hospitals, $4,000 to $20,000 each; and thirty hotels, $9,000 to $25,000 each. The loss per building for 35 large office buildings was set at $11,000 to $35,000 per year.

An economic loss that should not be overlooked is property value depreciation due to undesirability of land in dirty, smelly areas. It is not unusual(107) to find property values $2,000 per house less in neighborhoods affected by air pollution than in nonpolluted areas. The City of St. Louis(21) estimated that before air pollution control measures were enforced in 1941 property values had declined at least $25,000,000 per year for ten years. Another estimate gives the national annual loss of real estate values due to air pollution as being over $200,000,000.

Since the rate of corrosion of many metals is increased by air pollution, economic losses are sustained. Replacement of metal articles must be made more frequently and protective covering must be provided. In metal building components an increased factor of safety must be used in design to compensate for the effects of corrosion, thereby increasing capital costs. Often more corrosion resistant metals, of greater cost, have to be used. One estimate(87) for the United States as a whole places the cost of atmospheric corrosion at two billion dollars a year, but no estimate is made of the portion due to atmospheric pollution. In Great Britain in 1954, corrosion losses due to atmospheric pollution were estimated at 90 million dollars per year with the reservation that this estimate is possibly low(87). The Transmission Department of the British Electricity Authority estimated(87) that air pollution costs them 3,000,000 dollars annually because of corrosion and such items as the cleaning and washing of pollutants from insulators. The cost is mainly for replacements, increased application of protective coatings, and for more substantial design and more expensive corrosion resistant materials.

The cost of repairing stone buildings effected by air pollution is large. A 1924 estimate(62) for Great Britain shows an annual cost of 430,000 dollars for official buildings alone. Recently the cost attributed to corrosion for repair of two stone buildings was reported as $2,000,000 for Brooklyn Borough Hall and $3,000,000 for City Hall, both in New York City(26).

Reduction of sunlight intensity solely because of air pollution has been reported(87) as high as 75 percent in some cities, occasionally higher. Such smoky and hazy atmospheres necessitate extra artificial lighting in stores, homes, and streets. It is difficult to distinguish between the effect on the cost of lighting of adverse, but natural, meteorological conditions, and air pollution. However, a 1913 report on the city of Pittsburgh (101) stated that one-fourth of the home and one-third of the office electric bill was due to darkened man-polluted skies. A 1952 report(87) for the same city, even after a vigorous air pollution program had been in effect for some time, estimated an extra cost for electricity of $5.00 for each inhabitant of the metropolitan area. Data gathered in the Detroit-Windsor area indicate that daylight illumination is reduced 8 to 16 percent of that found in semirural areas.

Some of the losses on which it is difficult to place a definite monetary value should be recognized. One such item is the loss to a community of citizens who prefer the cleaner air of the suburbs to more polluted air of the city, with the resultant loss of revenue and business. Too, a polluted atmosphere may discourage such industries as textiles and foods which require a clean atmosphere, from locating in a city even if every other aspect is favorable. Also difficult to assess are the losses from air pollution due to curtailment of air transportation service and lowered manufacturing productivity due to decreased efficiency of workers.

Chapter XI

RELATION BETWEEN POLLUTION LEVELS AND METEOROLOGICAL FACTORS

If there were no means of carrying away gases and particles from the location of their introduction into the atmosphere, the air would locally become polluted to an intolerable degree. Fortunately, there are atmospheric processes that dilute and disperse the contaminants. The diluting capacity of the air varies from day to day and from hour to hour. At certain times the atmosphere is an excellent dispersing medium but at other times this is not the case. Therefore, it is important to study the variations in atmospheric diluting capacity.

Not only does the state of the atmosphere have an effect on pollution levels, but there is also the converse effect of pollution levels on atmospheric conditions. It has been shown, for example, that the Ruhr region in Germany has measurable rain or drizzle on 20 more days per annum than do nearby less industrialized areas(78). This difference may be caused largely by the ability of rain drops to form on the condensation nuclei emitted from the industrial pollutant sources. Robertson(58) demonstrated that the frequency of low-temperature fog at Edmonton Airport is influenced by moisture from combustion of natural gas used for heating in the city.

Broad-scale weather features over large areas of the North American Continent govern, to a certain extent, the pollution levels in specific localities. Very often a "smoky day" in Detroit will correspond to a "smoky day" in Cincinnati. Micrometeorological features are influenced by local topography, land contours, bodies of water, and the position and heights of buildings, woods, and fields. These will all superimpose their influence upon the broad-scale weather features and therefore modify the pollution-dispersing capacity of the atmosphere. It is necessary, therefore, to describe the meteorological factors on both a broad-scale and a micrometeorological basis.

The United States Weather Bureau and the Meteorological Branch of the Canadian Department of Transport operate a number of first-order synoptic, hourly weather reporting stations, and climatological stations in the Detroit-Windsor area (Chapter V). Radiosonde ascents were make at Toledo and also at Mount Clemens until September 1956. Data from these stations were used in addition to data collected by the Technical Advisory Board staff.

Some special instrumentation was obtained for the International Joint Commission air pollution study. This included a Bendix-Friez aerovane, two illuminometers, a modified Nash and Thompson rainfall recorder, an assembly of resistance thermometers on an 1100-foot TV tower to measure vertical temperature differences, and a transmissometer to measure visibility. The Bendix-Friez aerovane(97, 95) became operational in February 1953, at the Peter and Chappell Streets sampling station in Windsor. The aerovane was mounted at a height of approximately 20 feet above the ground and the recorder was located in the sampling shelter house. A standard Nash and Thompson rainfall recorder(102) was modified and became operational at the Peter and Chappell Streets sampling station in Windsor in May 1954. The modification consisted of connecting a Meteorological Branch standard tipping bucket rain gauge detector(90) to the Nash and Thompson electric impulse counter. The other special instruments are described later in this chapter.

WIND TURBULENCE AND VERTICAL MOTION OF AIR

Anemometer records show that there are many apparently random eddies in the wind, ranging in duration from a fraction of a second to many minutes. The rate of diffusion is dependent upon the size and energy of the eddies. The unusual case when there is no turbulence is known as "laminar flow" and rarely occurs in the natural atmosphere. The three-dimensional coefficients of eddy diffusivity are not collectively nor individually constant in time or space. (68) Furthermore, it has been shown that the coefficients increase with the scale of the phenomenon. (2) Godson(23) explains this simply by reference to the diffusion of smoke from a stack. "Near the stack, the smoke plume is narrow. Large eddies are effective in moving the plume bodily, but not in diffusing it or breaking it up. Only small eddies, smaller than the dimensions of the plume, can actually cause a spreading of the plume. At large distances from the stack, the smoke plume has much larger cross-wind dimensions, and the larger eddies are now effective in dispersing the smoke. Essentially, therefore, the eddy diffusivities must increase with distance from the stack."

There are two main types of low-level turbulence to consider in the dispersion of air pollutants. Mechanical turbulence is caused by friction with the ground. The size of the eddies formed depends upon the roughness of the ground and the speed of the wind. A mechanical eddy can cause a plume of smoke to loop, with the smoke reaching the ground in high concentrations for short intervals. Thermal turbulence may be caused by cold air blowing across the Great Lakes in the autumn or winter. Thermal turbulence producing a similar effect may also be caused by daytime heating of the ground by the sun. This effect will be a maximum in summer and thus diffusion is usually rapid on a fine summer afternoon.

Smith(65) has described four relatively discrete classes of turbulence traces from a Bendix-Friez aerovane located on a 420-foot tower at Brookhaven. He has applied his four classifications to synoptic situations and developed a method of prediction applicable to dispersion of pollution from a single stack. This classification should be useful for the study of pollution in an industrial city.

The vertical motion of air is intimately connected with turbulence, since air is carried up or down by means of eddies. Both turbulence and vertical motion of air are controlled to a large extent by the lapse rate, or rate of decrease of temperature with height. However, the relationship is complex. For unsaturated air, when the actual lapse rate is greater than the dry adiabatic, i.e., 5.4°F./1000 ft., the air is unstable. If an initial upward displacement is given to a parcel of air, i.e., by mechanical turbulence, the air will continue to rise. This condition is favorable to rapid diffusion. It usually occurs in the lowest levels of the atmosphere when cold air is blowing across warm ground or water, or when the ground is heated by the sun during the daytime. When the actual lapse rate is less than 5.4°F./1000 feet, vertical motions are suppressed and the air is said to be stable. When there is an inversion, i.e., an increase in temperature with height, turbulent vertical motions and diffusion are almost completely checked. Experiments at Brookhaven National Laboratory(65) and at Trail, British Columbia(30) have shown that during inversions stack effluents can travel up to 25 miles without undergoing great dilution.

Inversions may form in several ways:

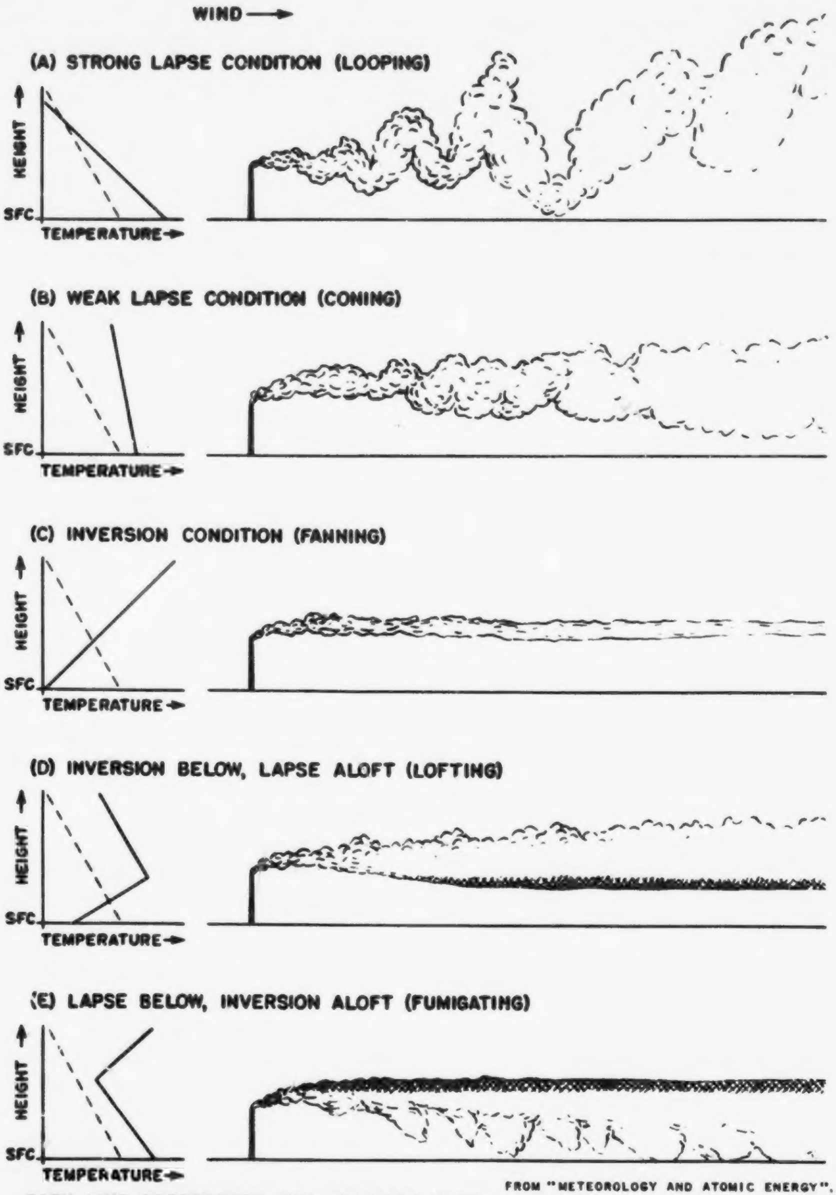
a. Nocturnal radiation occurring with clear skies and light winds will produce falling temperatures over a land surface with little change aloft. If surface cooling is sufficient, an inversion will develop. Usually the inversion will disappear the following morning when the sun heats the ground;

b. An inversion will often be found at a frontal surface aloft. If the surface front is stationary, the inversion may persist for a considerable length of time at the same level;

c. An inversion may develop when relatively warm air blows across a cooler surface. This type of inversion can occur, for example, when warm air flows across a snow-covered surface during the winter, or across a large lake in the spring or summer. During warm summer days the persistence of smoke plumes from vessels over the Great Lakes is quite noticeable;

d. An inversion may form when subsidence develops in the free atmosphere. A relatively steep lapse rate is maintained in the upper portion of the subsiding air, while a slight, or even reversed lapse rate is produced in the lower portion. Subsidence may be a broad-scale feature of an air mass covering several hundred square miles or it may be of micrometeorological scale, i.e., cold air sliding down the side of a hill. Broad-scale subsidence usually occurs(54) in high pressure areas, while upward motion occurs in low pressure centers and with fronts.

Stack gas dispersion is strongly influenced by vertical motion in the atmosphere and by other factors (111). Looping (Figure XI-1-A) occurs with very unstable conditions. Eddies in the wind flow occasionally carry the stack gas to ground levels for a few seconds. Coning (Figure XI-1-B) occurs when the lapse rate is between the dry adiabatic and the isothermal.


WIND →
(A) STRONG LAPSE CONDITION (LOOPING)
HEIGHT →
SFC.
TEMPERATURE →
(B) WEAK LAPSE CONDITION (CONING)
HEIGHT →
SFC.
TEMPERATURE →
(C) INVERSION CONDITION (FANNING)
HEIGHT →
SFC.
TEMPERATURE →
(D) INVERSION BELOW, LAPSE ALOFT (LOFTING)
HEIGHT →
SFC.
TEMPERATURE →
(E) LAPSE BELOW, INVERSION ALOFT (FUMIGATING)
HEIGHT →
SFC.
TEMPERATURE →

DASH LINE REPRESENTS DRY ADIABATIC RATE

FROM "METEOROLOGY AND ATOMIC ENERGY", U.S. DEPT. OF COMMERCE, WEATHER BUREAU, P. 59, JULY 1955

Figure XI-1. Schematic Representation of Stack Gas Behavior under Various Conditions of Vertical Stability

The plume is more in the shape of a cone. In fanning, (Figure XI-1-C) which occurs with inversions, the plume shape is a ribbon. Lofting (Figure XI-1-D) occurs when there is an inversion below and neutral or unstable conditions above the plume. It can occur in the evening when a nocturnal inversion is developing upwards. Fumigation (Figure XI-1-E) occurs when there is an unstable lapse rate below and an inversion above the plume level. It can take place in the morning when a nocturnal inversion begins to "burn off". Relatively high concentrations of pollution can be brought to the ground from stack level by this process. Hewson and Gill (30) explained the midmorning peak of ground-level sulfur dioxide concentrations at Trail, British Columbia in this manner.

TELEVISION TOWER TEMPERATURE OBSERVATIONS

Four resistance thermometers were installed on the television tower used by Station WJBK-TV by special arrangement with the Storer Broadcasting Company. The thermometers were 20, 300, 600, and 870 feet above the ground. The tower is located ten miles to the northwest of downtown Detroit in flat, grassy country. There are no industrial areas in the vicinity. A main highway passes one-half mile to the west. A large shopping center is situated one-half mile to the south southeast and there is a residential area about a quarter of a mile to the east. Standard Minneapolis-Honeywell resistance thermometers were used. These thermometers were calibrated by the Instrument Division of the Meteorological Branch, Toronto (Table XI-1). Because of the nature of the equipment, the errors probably remain constant with time. Temperatures measured on the TV tower have not been corrected for calibration error. Provision is made to ventilate the thermometers by inserting them through a "T" into a copper duct. Air is drawn constantly through the duct by means of a Meteorological Branch type 1 motor psychrometer pump. The thermometer and the intake of the duct are surrounded by a galvanized iron housing, painted white, to minimize the effect of solar radiation. The assembly at the 20 foot level on the TV tower is as shown in Figures XI-2 and XI-3. The thermometers are connected by cable to a Brown Electronik 8-point recorder,(86) located in the television station control building on the ground. Four circuits are shorted out. The other four circuits give a temperature reading for each level in succession, the entire cycle comprising four minutes. The recorder chart drive moves at a rate of four inches per hour so that a single chart provides a record for two weeks. Temperatures can be read from the chart to the nearest half degree F. Installation of the equipment on the tower was completed on July 18, 1955. Initial tests indicated that shielding and ventilation were satis-

Table XI-1. Calibration Data for Thermometers Used on TV Tower

Temp. degrees F.	Error in degrees F.				
	20-ft. unit	300-ft. unit	600-ft. unit	870-ft. unit	Spare unit
- 18	-0.2	-0.1	0.0	0.0	-0.1
10	-0.4	-0.2	-0.2	-0.2	-0.2
30	-0.4	-0.4	-0.4	-0.4	-0.4
45	-0.6	-0.6	-0.6	-0.6	-0.6
60	-0.6	-0.6	-0.6	-0.6	-0.6
75	-0.4	-0.4	-0.4	-0.4	-0.5
90	-0.4	-0.3	-0.4	-0.3	-0.3
105	-0.1	-0.1	-0.2	-0.1	-0.2

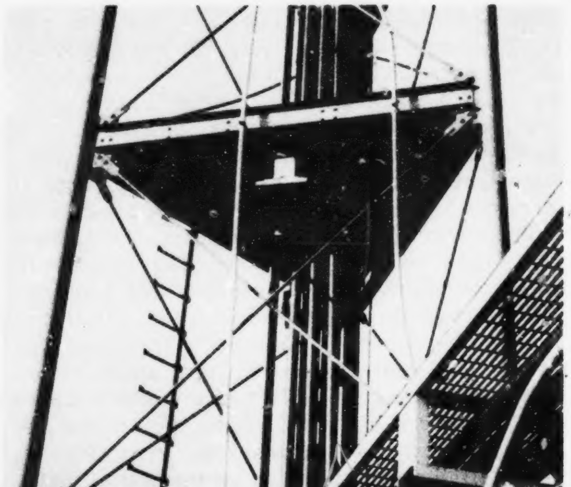


Figure XI-2. General View of a TV Tower Thermometer Installation

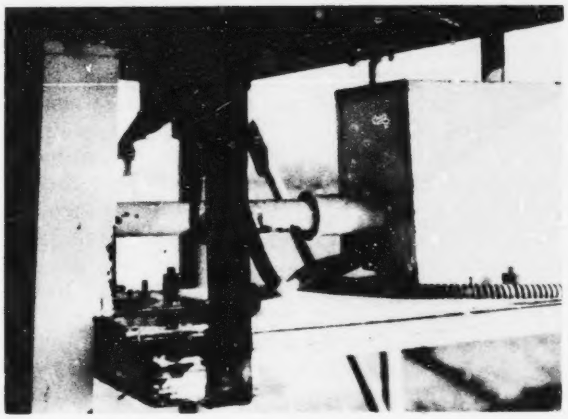


Figure XI-3. Detail View of a TV Tower Thermometer Installation.

factory except at the 870 foot level where radio-frequency interference was raising the temperature about 2.5 degrees whenever the transmitter was on. Additional shielding added on July 27, 1955 overcame this difficulty. A complete recheck was done on October 17 and 18, 1956 by inserting the spare unit at all levels in succession. There was no significant variation except at the 600 foot level where the connection was wet. The spare unit was left at the 600 foot level and the connections at all levels were retaped. One other source of error is the heating of the tower itself by the sun. If the four units were similarly placed with respect to the tower platforms, the effect would be nearly the same at all levels. Since the study is concerned with temperature differences, a constant bias at each level would not be important. The location of the four units originally satisfied this requirement. However, in September 1955, at the request of the Storer Broadcasting Company, the 20 foot level unit was moved from above to below the platform. The effect of the move cannot be assessed quantitatively from the record because of weather variations from year to year. A qualitative examination suggests that at night, the 20 foot to 300 foot level temperature difference was not significantly changed after the September 1955 move, but that during the day, the 20 foot to 300 foot level temperature difference was reduced after the September 1955 move, the amount varying with the amount of sunshine, wind, and turbulence, etc. It was further indicated that the 20 foot thermometer gave a relatively lower temperature below the platform than it did above and that on sunny, unstable afternoons, the difference sometimes exceeded 2°F. To summarize, the tower records are believed to give a true picture of the vertical structure of the atmosphere at night. During the day, a more stable picture is presented of the lowest 300 feet than actually exists. Slight changes in the clutch tension of the recorder chart drive mechanism have made the record unreadable at times accounting for a loss of about one-third of the data during the first two years of operation.

Temperature measurements taken from the WJBK-TV tower installation were abstracted from the charts at hourly intervals. The period of observations included in this report extends from July 27, 1955 to July 31, 1957, and resulted in a total of 11,803 usable hourly readings. Because of irregular equipment failure, more data are available from some seasonable periods than others, with 3,481 for the months of December through February; 3,869 for March through May; 2,183 for June through August; and 2,270 for September through November. A monthly data summary, (Figure XI-4) was prepared. The code was designed to provide the greatest amount of

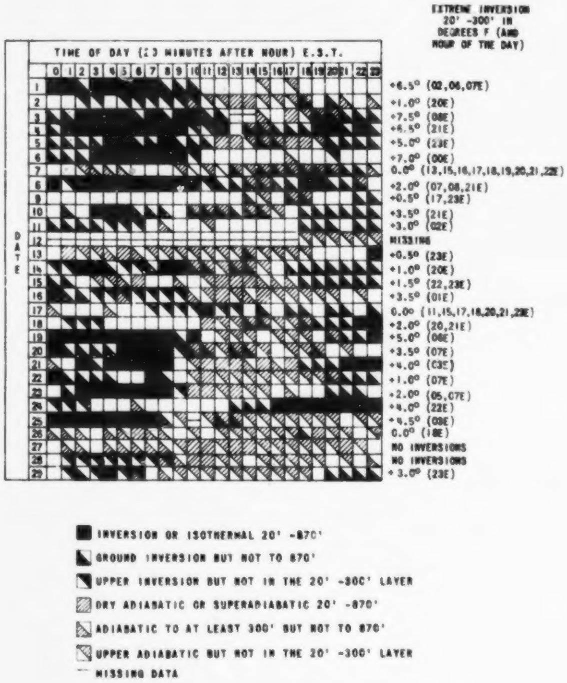


Figure XI-4. Example of Television Tower Temperature Data Summary.

monthly information on a single sheet of paper in an understandable form. Seven different types of vertical temperature profiles were tabulated. They are:

Type 1. Inversion, 20 foot to 870 foot levels.

Type 2. Ground inversion, but not to 870 foot (neutral lapse rate aloft).

Type 3. Upper inversion, but not in the 20 foot to 300 foot layer (neutral below).

Type 4. Ground inversion, adiabatic layer aloft.

Type 5. Adiabatic layer below, inversion aloft.

Type 6. Dry adiabatic layer or layers, with or without neutral layers.

Type 7. Neutral (between adiabatic and isothermal) - 20 foot to 870 foot.

Isothermals are included with inversions, while superadiabatic lapse rates are included with dry adiabatics.

During daylight hours, as previously pointed out, the 20 foot level unit, after the change in location in September 1955, had a temperature bias in relation to the readings from the other three levels. The bias does not appear to be constant but varies with the amount of cloudiness, turbulence, etc. The visual summaries give a more stable picture of the lowest 300 feet during the daytime than actually exists. For this reason, tabulations of profiles of type 6 have not been subdivided into the three groupings displayed on the visual summaries.

The main features of the diurnal frequency patterns are:

Type 1. Inversion in all layers (Figure XI-5):

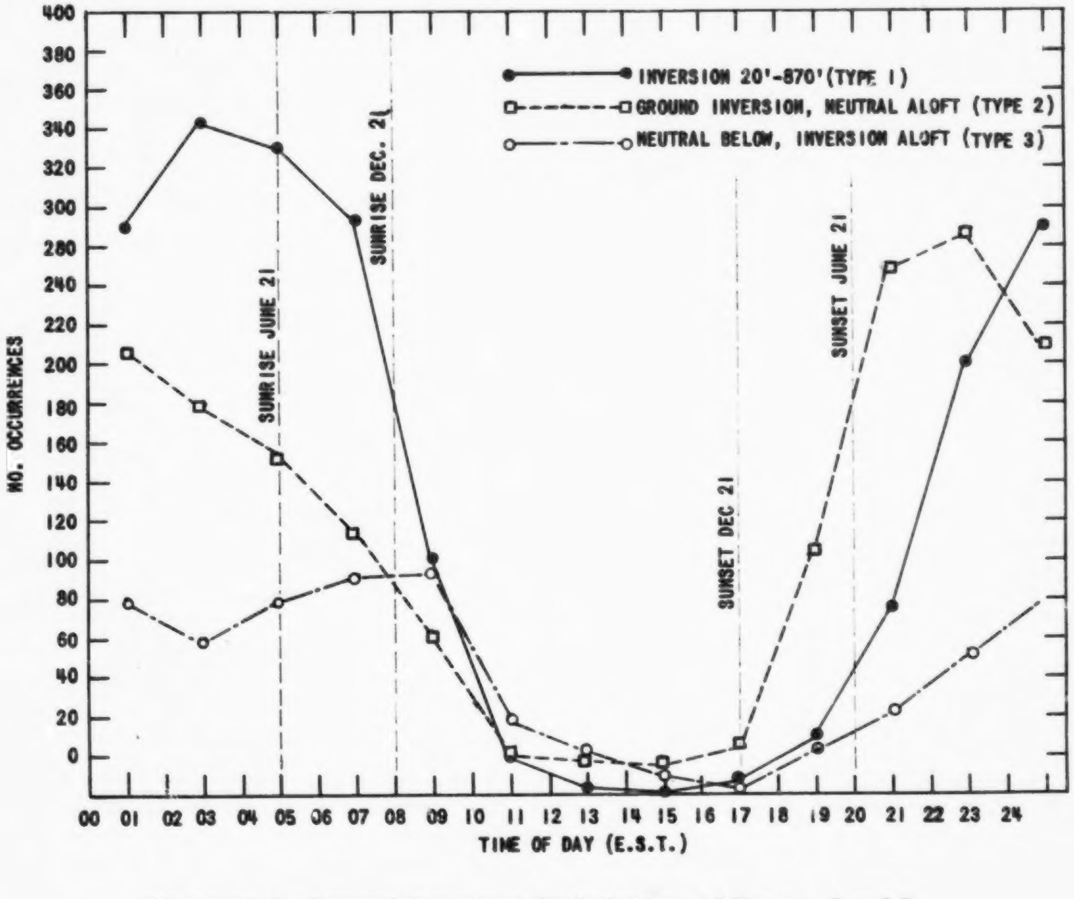


Figure XI-5. Dirunal Frequency Distributions of Type 1, 2 and 3 Vertical Temperature Profiles

There is a maximum frequency just before sunrise and a minimum in the afternoon. The curve is in phase with the pattern of nocturnal radiation and daytime insolation.

Type 2. Ground inversion, neutral aloft (Figure XI-5): The afternoon minimum is similar to that of the Type 1 curve; however, the maximum occurs in the late evening. This is explained by the fact that evening radiation inversions are relatively shallow but build upwards to higher levels during the night. From midnight until 11 a.m. there is a greater probability of a Type 1 rather than a Type 2 inversion.

Type 3. Neutral below, inversion aloft (Figure XI-5): The minimum frequency again occurs in the afternoon, but there appear to be two maxima. The principal maximum occurs in the morning after sunrise and is explained by the fact that the inversion disappears first near the ground. The secondary maximum, occurring shortly after midnight, may be due to random sampling variations. Apart from occurrences shortly after sunrise, Type 3 profiles will be mainly frontal. The secondary maximum could be explained by a tendency for nocturnal inversions to build upwards and join with frontal inversions after 1 a.m. The relatively low frequency of Type 3 profiles in the afternoon suggests that the sun is very successful in breaking down frontal inversions to at least 870 feet at the tower site.

Type 4. Ground inversion, adiabatic aloft (Figure XI-6): There is a minimum frequency near sunrise and a marked maximum just after sunset. The secondary minimum just before sunset is believed to be caused by random sampling variations. The evening maximum is a transition period between daytime adiabatic conditions and nocturnal inversions.

Type 5. Ground adiabatic, inversion aloft (Figure XI-6): The curve is relatively flat, but

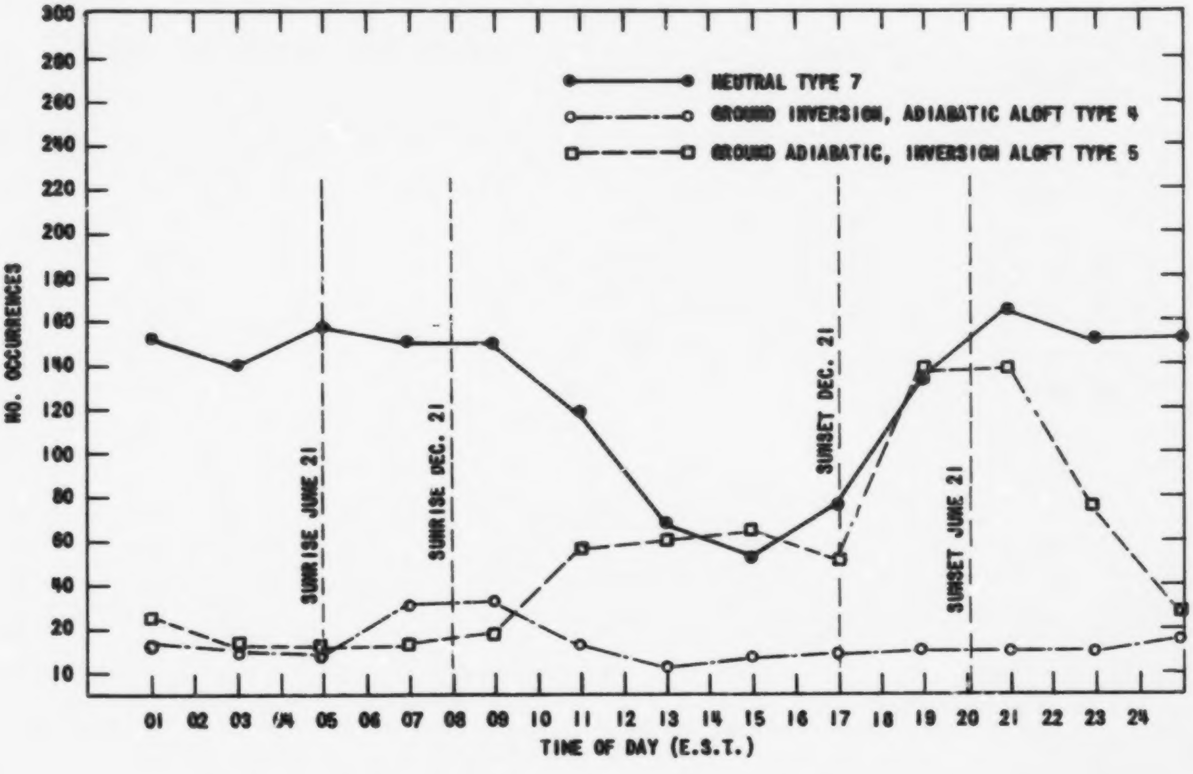


Figure XI-6. Diurnal Frequency Distributions of Type 4, 5 and 7 Vertical Temperature Profiles

there is a slight maximum just after sunrise, which is explained by the Hewson "fumigation" phenomenon.(30)

Type 6. Adiabatic layer or layers with or without neutral layers (Figure XI-7): There is a late afternoon maximum frequency and a nocturnal minimum, as would be expected. Note that the vertical scale in Figure XI-7 is not the same as in Figures XI-5 and XI-6.

Type 7. Neutral (Figure XI-6): There is an afternoon frequency minimum with a nighttime plateau. Solar insolation is the cause of the afternoon reduction in frequency.

Inversions of temperature profile Types 2, 3, 4, and 5 show little seasonal frequency variation (Table XI-2 and Figure XI-8). Type 1 is a maximum in the summer and fall during hours of darkness. During the summer and fall an inversion of some sort occurred at least 75 percent of the time at night. The nighttime minimum frequency appeared in the winter, while the daytime minimum shifted ahead to spring. There is a seasonal variation in neutral lapse rates, both night and day, with a maximum frequency in the winter and minimum in the summer. Percentage frequencies are quite small at all times of the year, ranging from 9 to 17 percent. Hence, a neutral lapse rate is not a "normal" lapse rate at the tower site. This is in agreement with previous findings (111) that "The neutral lapse rate is often referred to as 'average' conditions. This may give an incorrect impression since measurements show that in a continental area

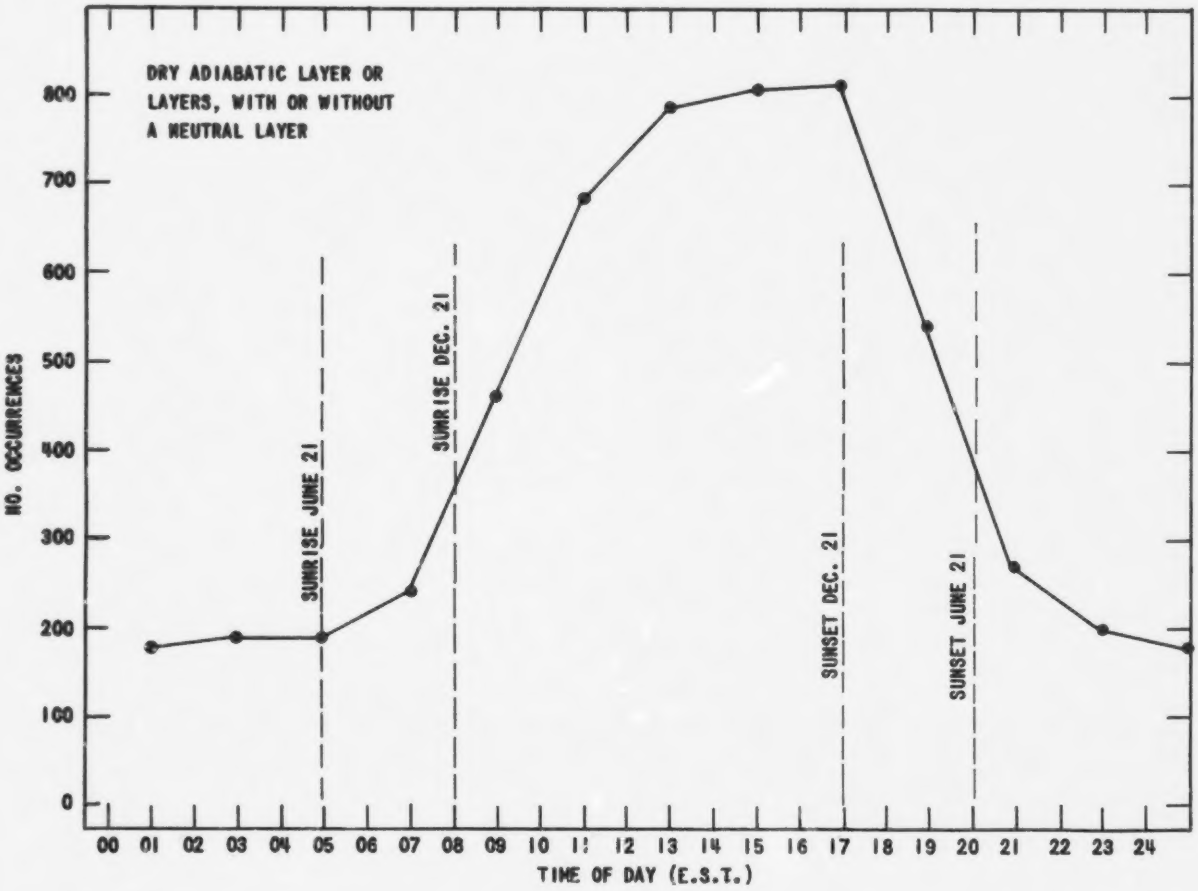


Figure XI-7. Diurnal Frequency Distribution of the Type 6 Vertical Temperature Profile

Table XI-2. Seasonal Variation in Frequency of Types of Vertical Temperature Profiles - (July 27, 1955 to July 31, 1957)

Time span and season	Percent frequency of occurrence						
	Type 1	Type 2	Type 3	Type 4	Type 5	Type 6	Type 7
All cases							
December, January, February	10	13	7	5	1	47	17
March, April, May	11	11	7	5	1	51	13
June, July, August	20	14	5	8	3	40	9
September, October, November	24	19	4	6	1	38	10
Night--0100-0500 hrs. EST (incl.)							
December, January, February	19	19	11	1	1	30	19
March April, May	28	20	11	2	1	23	17
June, July, August	50	19	8	2	2	6	12
September, October, November	50	22	5	1	0	12	11
Day--1200-1600 hrs. EST (incl.)							
December, January, February	1	2	2	5	0	81	9
March, April, May	0	1	1	5	0	86	7
June, July, August	0	3	1	8	2	81	4
September, October, November	1	2	1	8	0	83	5

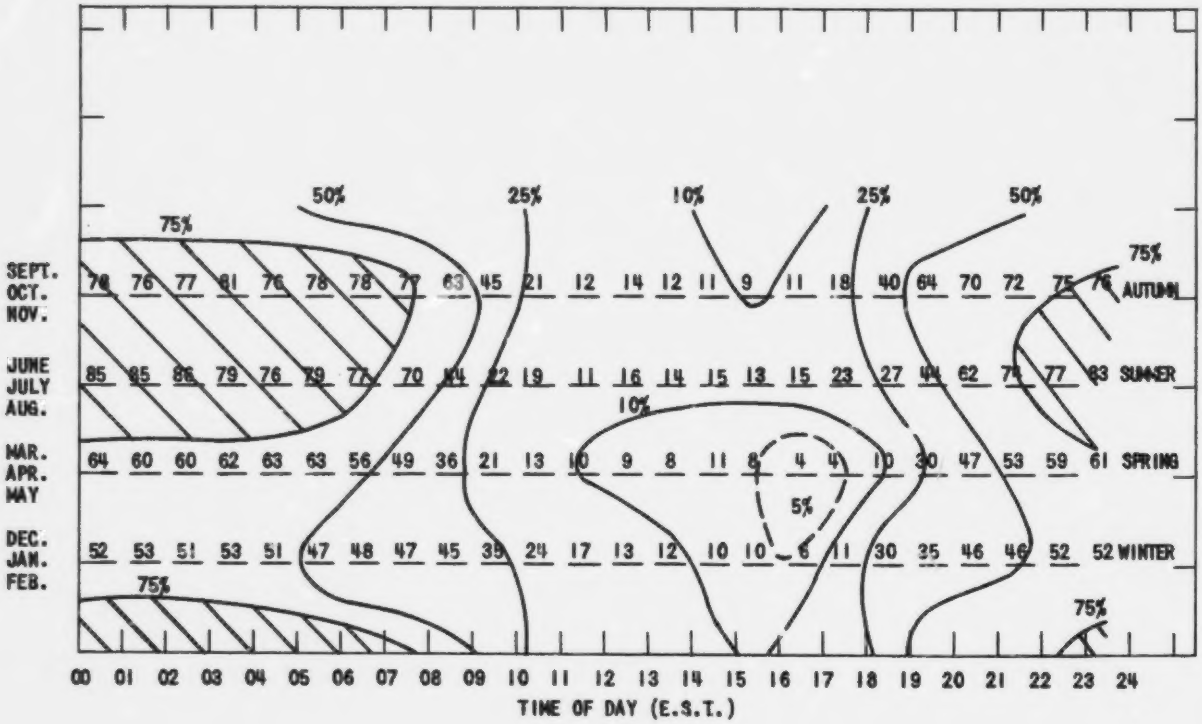


Figure XI-8. Percentage Frequencies of All Types of Inversions by Seasons

the temperature profiles are most frequently superadiabatic by day and isothermal or inverted at night." The greatest percentage frequency of adiabatic temperature profiles at night is in the winter. Unstable air is maintained at night by the strong advection of cold air over a warmer surface, primarily a winter phenomenon. During the day, there is no clearly marked seasonal trend in occurrence of adiabatic profiles.

Monthly inversion extremes that occurred in the 20 to 300 foot layer during the two-year period (Table XI-3) were between 6 and 17.5 degrees F.

Table XI-3. Extreme Monthly Inversion Intensity--20-to 300-Foot Levels on the TV Tower - (July 27, 1955-July 31, 1957)

Month	Extreme inversion in degrees F.	Month	Extreme inversion in degrees F.
January	11.0	July	10.0
February	12.5	August	11.5
March	16.0	September	17.5[a]
April	13.0	October	15.5
May	12.0	November	7.5
June	14.5	December	6.0

[a] September 13, 1955

From the visual monthly summaries, a count was made of the number of consecutive hours of temperature profile codes 1 to 5 (an inversion or isothermal in some or all layers). Breaks of one hour caused by missing data or other types of profiles were neglected. The relative heights of the four curves obtained (Figure XI-9) should not be compared because of the seasonal bias in the amount of available data. However, a number of conclusions may be drawn. All four curves have a characteristic shape. The highest dura-

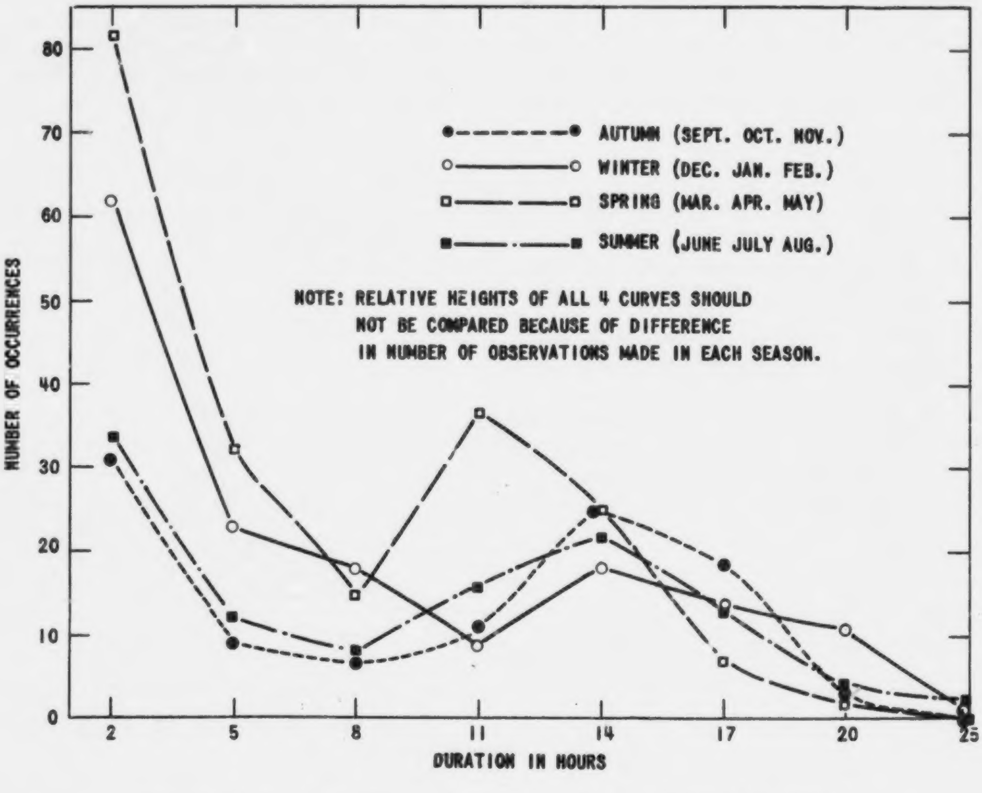


Figure XI-9. Duration of All Types of Inversions by Season

tion frequency is in the 1- to 3-hour period, with a secondary maximum in the 10- to 15-hour period. There is a seasonal shift in the position of the secondary maximum. A subjective smooth-curve estimate of the secondary peaks, which are believed to be a measure of the most probable duration of nocturnal inversions, indicates a duration of 15 hours in winter and autumn, 14 hours in summer and 11-1/2 hours in spring. The winter secondary peak is much flatter than in the other three seasons. This is attributed to the fact that the sun is relatively ineffective in the winter in breaking down inversions.

The time of onset of inversion periods (Figure XI-10) shows a pronounced evening peak, the actual time shifting with the seasonal changes in the time of sunset. At other times of day the four curves are relatively flat and variations are believed to be caused by random sampling.

The most probable morning break-up time of an inversion may be derived by studying Figures XI-9 and XI-10 together. For example, in summer the most probable duration is 14 hours; therefore, the most probable break-up time is 10 a.m. This is a time when inversion will disappear up to the top level on the tower. Inversions in the lowest 300 feet have a probable disappearance time earlier than 10 a.m.

Two years is a relatively short period of time in climatological studies. To accumulate a longer period of record and allow further correlation of TV tower data with air pollution data and other meteorological variables, arrangements were made on the termination of field work for the International Joint Commission for continuation of the TV tower studies by the University of Michigan.

Application of the TV tower data

To illustrate how A.I.S.I. strip filter paper sampler measurements may be related to vertical temperature profiles, Tables XI-4 and XI-5 were prepared. The Coh per 1000 foot values are from two hourly samples taken at the Peter and Chappell Streets sampling stations in August 1955. The winds are those measured at the Detroit City Airport at 20 minutes past the hour of midpoint of the A.I.S.I. samples. The vertical temperature profiles are the TV tower differences between temperatures at the 870- and 20-foot levels. Each table represents 16 hours. The remaining 8 hours were purposely excluded because they represent the transition periods between day and night.

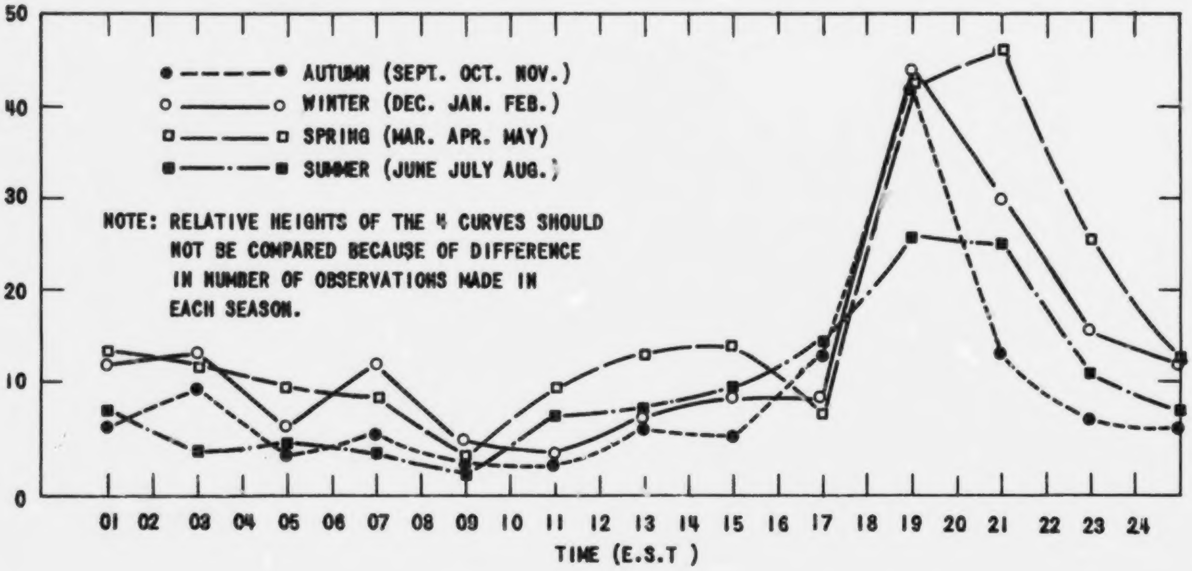


Figure XI-10. Time of Onset of Inversion Periods by Seasons

Table XI-4. Relationship Between Vertical Temperature Profiles, Wind Speed, and Pollution Levels - (August 1955)

	Wind Speed			
	1-3 mph	4-6 mph	7-9 mph	10 mph & over
Night hours --2320 to 0620 EST incl.				
870-foot minus 20-foot temperature	+7.1	+5.1	+4.9	-0.9
Coh/1000 foot values	1.81	1.47	1.30	1.03
Number of cases	12	27	22	7
Wind direction frequency:				
NNE-E	4	5	5	0
ESE-S	2	5	3	1
SSW-W	3	8	10	3
WNW-N	3	9	4	3
Day hours --0920 to 1620 EST incl.				
870-foot minus 20-foot temperature	-	-5.2	-4.9	-5.9
Coh/1000 foot values	-	0.89	0.77	0.67
Number of cases	Nil	10	18	32
Wind direction frequency:				
NNE-E	-	5	2	8
ESE-S	-	3	4	0
SSW-W	-	1	8	9
WNW-N	-	1	4	15

Table XI-5. Relationship Between Vertical Temperature Profiles, Wind Direction, and Pollution Levels - (August 1955)

	Wind Directions			
	NNE-E	ESE-S	SSW-W	WNW-N
Night hours --2320 to 0620 EST incl.				
870-foot minus 20-foot temperature	+5.9	+3.4	+4.6	+5.0
Coh/1000 foot values	1.81	0.90	1.43	1.44
Number of cases	14	11	24	19
Wind speed frequency:				
1-3 mph	4	2	3	3
4-6 mph	5	5	8	9
7-9 mph	5	3	10	4
10 mph & over	0	1	3	3
Day hours --0920 to 1620 EST incl.				
870-foot minus 20-foot temperature	-5.5	-5.1	-5.1	-6.0
Coh/1000 foot values	0.49	0.76	0.88	0.79
Number of cases	15	7	18	20
Wind speed frequency:				
1-3 mph	0	0	0	0
4-6 mph	5	3	1	1
7-9 mph	2	4	8	4
10 mph & over	8	0	9	15

Standard errors of all means were computed, although no tests for normal distribution were made. For physical reasons, the daytime vertical temperature profile distributions are likely to be skewed. In addition, all distributions will be biased because they were not drawn at random. Nevertheless the following general statements appear to be valid:

a. The mean Coh values are higher at night than during the day. This is directly in line with the respective vertical temperature profiles. During the night, turbulence decreases as the air near the surface tends to cool and form an inversion layer, a condition conducive to accumulation of pollution;

b. The mean Coh values decrease with increasing wind speed;

c. Northeasterly winds are associated with the highest pollution during the night and the lowest during the day. The distribution of wind speed frequencies, shown in Table XI-5, provides a partial answer since stronger winds contribute to lower pollution levels. However, it does not explain, for example, why during the daytime a northeast wind is associated with cleaner air than a northwest wind. The location of pollution sources in the surrounding area is partly responsible for the difference in pollution levels;

d. The two tables present evidence that the level of pollution is related to vertical temperature gradient, wind direction, and wind speed. The relationships might be sharpened if it had been possible to measure the four variables at the same site. There is a possibility of significant spatial variations between the TV tower, the Detroit City Airport, the Peter and Chappell Streets station, and heavily industrialized areas.

CLIMATOLOGY OF LOW LEVEL INVERSIONS AT MOUNT CLEMENS AND TOLEDO

No vertical temperature distribution data were available in the immediate Detroit-Windsor area beyond that obtained from the TV tower installation. The TV tower data are limited by the short period of record and the 870-foot maximum thermometer elevation. Therefore, use was made of summaries of radiosoundings prepared by the U.S. Weather Bureau Records Center for Mount Clemens, Michigan and Toledo, Ohio for the periods February 1948 to December 1950 and January 1946 to December 1950 respectively.(3) Balloons released at 1000 EST and 2200 EST provided the basic data. Inversions, in this discussion, include true inversion conditions and isothermal conditions. Winter is December, January and February and the other seasons follow accordingly at three month intervals.

Inversions occur a greater percent of the time at Toledo than at Mount Clemens (Table XI-6). On an annual basis, at 2200 EST, Toledo had an inversion 63 percent of the time corresponding to 55 percent at Mount Clemens. At 1000 EST, on an annual basis, Toledo had an inversion 26 percent of the time while at Mount Clemens inversions occurred 22 percent of the time. Chi-square tests for statistical significance of the different inversion frequencies at the two stations with one degree of freedom, gave values of 12.9 for 2200 EST and 1.6 for 1000 EST, on the original samples. The 1000 EST difference is not significant but the 2200 EST difference is significant at the one percent level. Therefore, inversions at Toledo at 2200 EST were significantly more frequent than at Mount Clemens. This significantly greater frequency of inversions at Toledo, suggests that conditions there are more favorable for formation of inversions produced by nocturnal cooling, the predominant inversion type at 2200 EST.

There was a marked difference in the percentage frequency of inversions at 2200 EST and 1000 EST. This is true of both locations and is caused by the frequent formation of nocturnal inversions by 2200 EST which are not ordinarily present at 1000 EST.

Seasonal frequency trends were similar at the two locations (Figure XI-11) (Table XI-6). Maximum frequency at 2200 EST occurred in summer and a minimum occurred in winter. At 1000 EST, the maximum frequency occurred in winter and the minimum in summer. Autumn appears to be the season when inversions are most likely to persist for longer periods.

Study of Table XI-6 and Figure XI-11 reveals that chances for a persistent inversion in the summer season are small since inversions at 1000 EST are at a minimum even though inversions at 2200 EST are at a maximum. In the fall, inversions at 2200 EST are frequent and inversions at 1000 EST are also frequent. It is indicated that a number of inversions will persist from 2200 EST through 1000 EST the follow-

Table XI-6. Seasonal Relative Frequency of Inversions at Mount Clemens and Toledo - (in percent)

Location of inversion base	Winter		Spring		Summer		Fall		Annual	
	2200	1000	2200	1000	2200	1000	2200	1000	2200	1000
Mount Clemens										
Surface	26	8	46	7	62	3	56	7	47	6
Above surface, below 1000 feet .	6	13	7	8	3	2	2	11	4	10
All below 1500 feet	38	30	57	20	66	12	60	24	55	22
Number of balloon ascents	188	197	212	215	245	250	238	251	883	823
Toledo										
Surface	39	14	49	4	73	1	67	5	57	6
Above surface, below 1000 feet .	3	19	9	11	2	6	2	19	4	14
All below 1500 feet	47	41	61	22	75	9	70	31	63	26
Number of balloon ascents	443	449	458	465	457	416	455	454	1813	1784

ing day and perhaps longer. The same general situation exists in the winter as in the fall but it is unlikely that the frequency of these persistent inversions will be as great. In the springtime, inversion frequency at 2200 EST increases but the frequency of inversions at 1000 EST decreases because of strengthening solar heating. Therefore, the chance of having persistent inversions in the springtime is low. Of the four seasons, fall is the season when inversions are frequent and most likely to persist and therefore the season most conducive to accumulation of pollutants in the atmosphere.

The distance above its base (surface or other) through which an inversion condition prevails has an effect on the volume of air available for dispersion of pollutants and on the behavior of stack plumes. The frequency distributions of inversion thickness in the range of zero to 3280 feet show a marked skewness with a well defined modal thickness in the range 450 to 900 feet (Figures XI-12 and XI-13). At Toledo, 23 cases of inversion thickness greater than 5000 feet occurred and one was over 9000 feet. At Mount Clemens, 15 inversions occurred with thicknesses over 5000 feet. Surface based inversions are generally thicker at 1000 EST than at 2200 EST. Skewness of thickness distribution is more pronounced at 2200 EST, especially at Toledo. For inversions based above the surface, thickness at 1000 EST is generally the same as or slightly less than that at 2200 EST.

Surface inversions at 2200 EST probably consist mainly of those formed by nocturnal cooling with a much smaller group consisting of those formed by advection, subsidence, or fronts. The sun's effect on nocturnal inversions is either to wipe them out by 1000 EST or shift them to a class of inversions based above ground. This is shown by the fact that at Mount Clemens there were 430 surface inversions at 2200 EST but only 56 at 1000 EST and at Toledo there were 1034 at 2200 EST but only 102 at 1000 EST. The number of low level inversions based above the ground at Mount Clemens changed from 39 at 2200 EST to 78 at 1000 EST and at Toledo the number increased from 74 at 2200 EST to 245 at 1000 EST. The advent of daylight, however, does not bring to an end the causative agent for advective, subsidence, or frontal class inversions. It is probably the emergence of this unaffected residue as the predominant class at 1000 EST that shifts the model thickness to slightly higher values. At Toledo, 69 percent of all surface

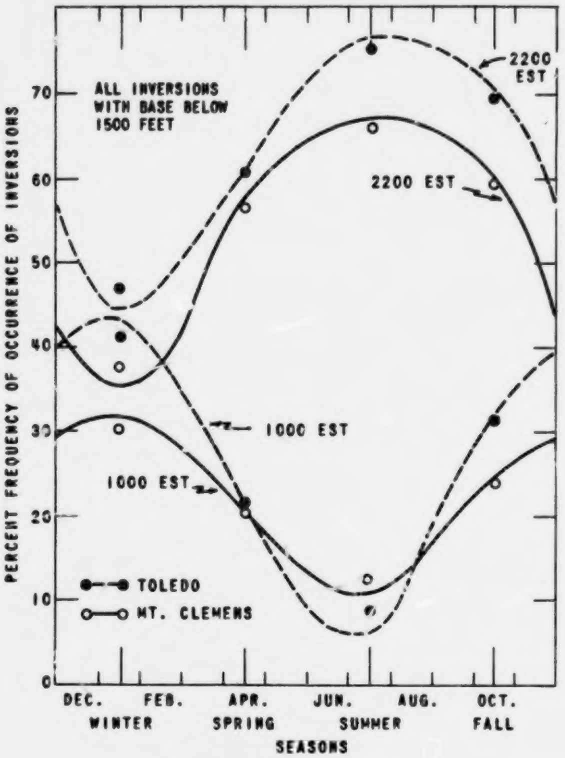


Figure XI-11. Relative Frequency of Occurrence of Inversions - Mount Clemens and Toledo.

based inversions at 1000 EST occurred with south to southwest winds of around 13 mph. indicating that most inversions existing at 1000 EST are caused by advection. If it is conceded that thickness is a direct function of age of the inversion, it follows that the advective, subsidence, or frontal types of inversions will be thicker than the comparatively newly formed nocturnal inversion. Therefore, the greater skewness of the thickness frequency curve for 2200 EST than the curve for 1000 EST is attributed to the fact that the preponderance of nocturnal inversions at 2200 EST is greater than the preponderance of advective inversions at 1000 EST.

The modal thickness of inversions at 2200 EST in Toledo is less than that at Mount Clemens because of the relatively larger proportion of thinner nocturnal inversions at Toledo (Table XI-7). At 1000 EST when nocturnal inversions play a minor role, the difference in thickness is small. It is concluded that the most probable thickness of inversions of the advective, subsidence and frontal types combined is about 800 feet and for nocturnal inversions, about 450 feet.

The intensity of inversions at Toledo at 2200 EST was generally greater than at Mount Clemens (Table XI-8) because at Toledo there was a larger proportion of nocturnal inversions which are more intense than inversions of other types. At 1000 EST there was little difference in intensity of inversions at the two sites. The

Table XI-7. Modal Inversion Thickness at Mount Clemens and Toledo (Calculated - data in feet)

Type of Inversion[b]	Season	Mount Clemens		Toledo	
		2200 EST	1000 EST	2200 EST	1000 EST
A	Winter	620	a	480	850
A	Spring	840	a	490	a
A	Summer	630	a	470	a
A	Fall	610	a	490	a
A	Annual	620	860	480	840
B	Annual	980	810	890	780

[a] Number of observations too few to define a mode

[b] Type A - Inversion based at surface. Type B - inversion based above surface but below 1000 feet.

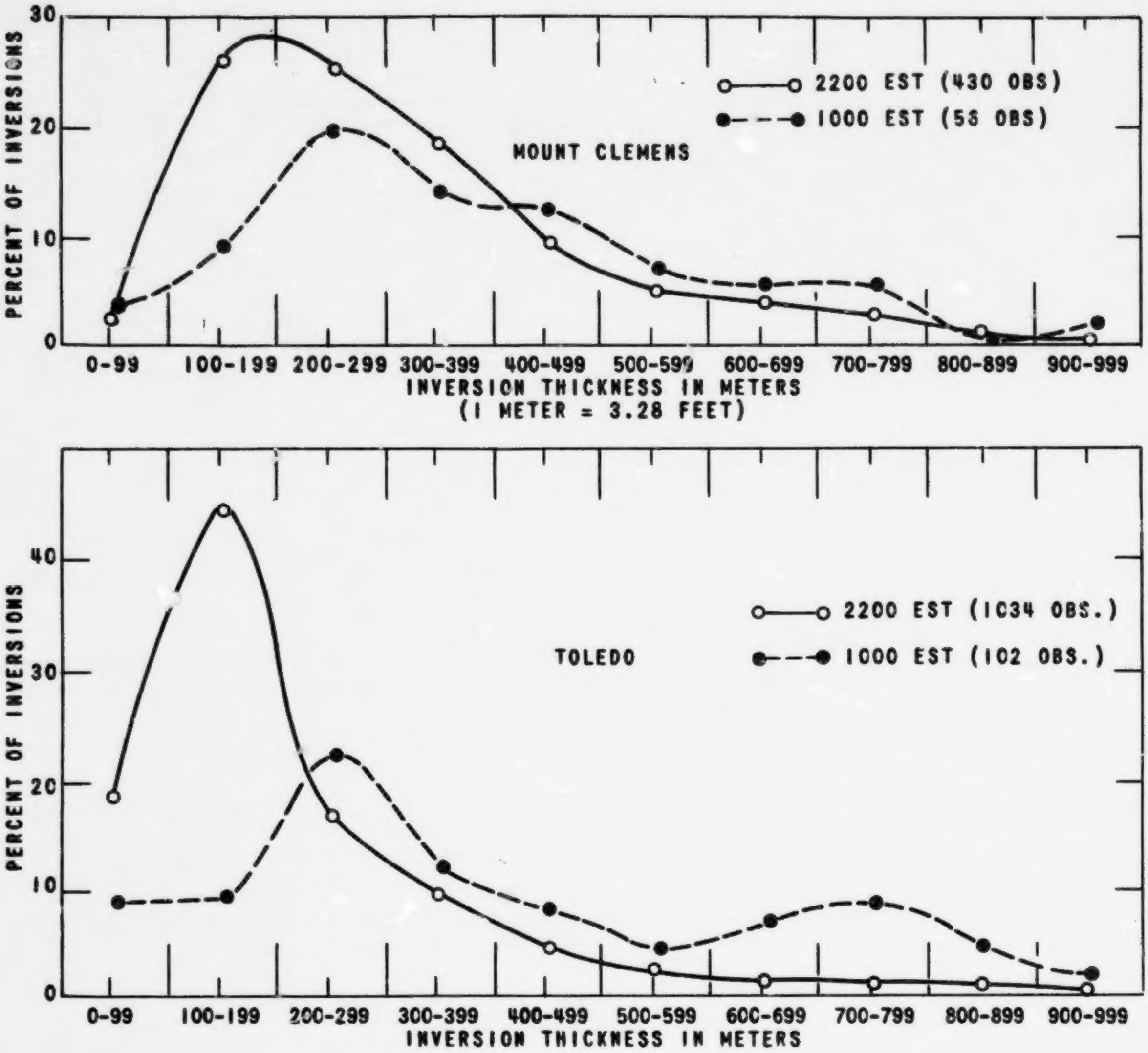


Figure XI-12. Thickness of Surface Based Inversions - Mount Clemens and Toledo

median lapse rate for all inversions of the advection, subsidence, and frontal types combined was about 8°C/Km. The median was an undetermined figure greater than 8°C/Km. for nocturnal inversions. The fall season experienced the most intense inversions at 2200 EST at both sites.

The proportion of time that inversions occur with south and southeast winds was greater than the proportion with any other wind direction at both Mount Clemens and Toledo (Table XI-9). This is due to the fact that with southerly flow a generally warmer air mass is advancing over cooler ground with resulting greater stability.

Surface wind speeds were generally less during inversions at both Mount Clemens and Toledo than when there were no inversions (Table XI-10). The effect was more pronounced at 2200 EST when most of the inversions were of the nocturnal radiation type than at 1000 EST when most inversions were of another type. The frequency of inversions with calm conditions

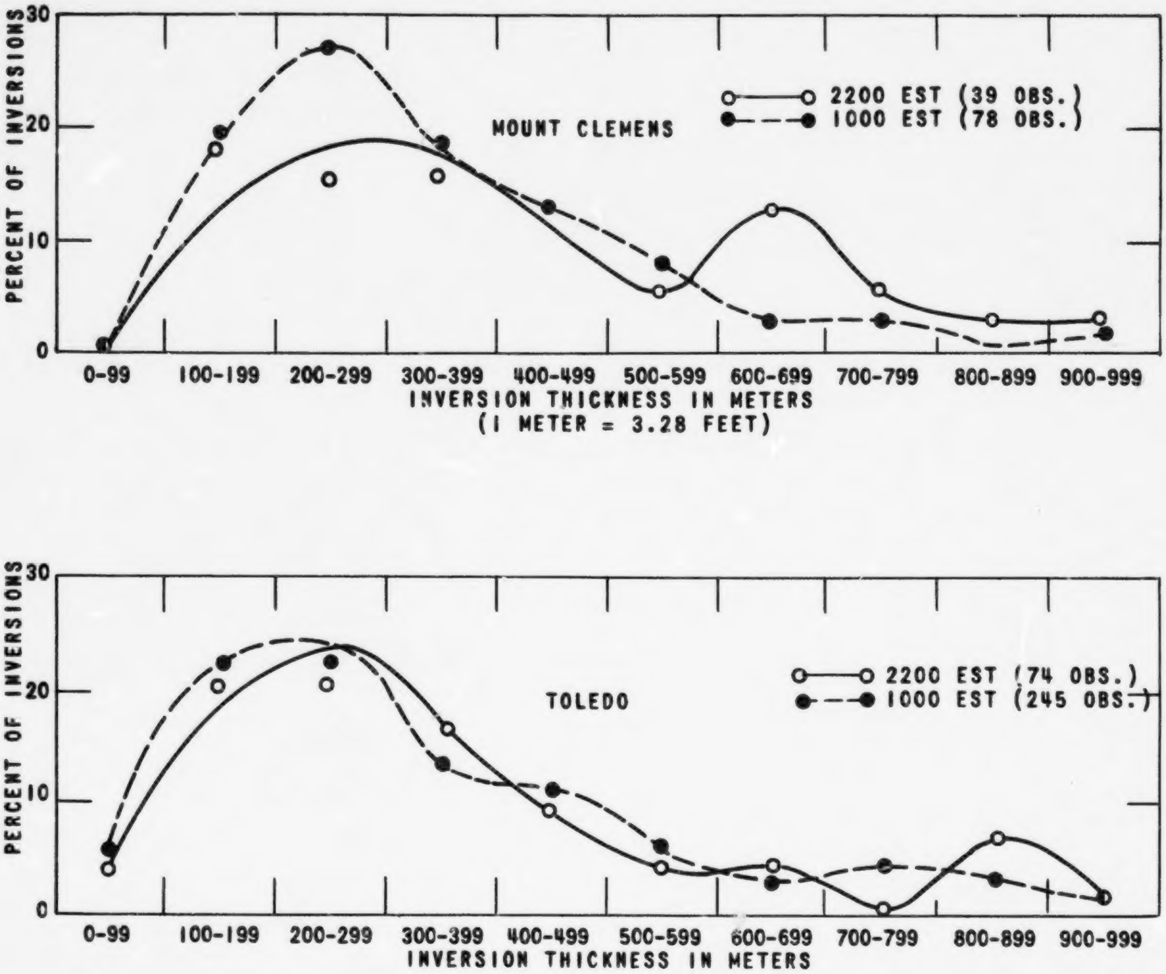


Figure XI-13. Thickness of Inversions Based Above Surface but Below 1000 Feet

was particularly high (Table XI-9).

For inversions of the frontal, advective, and subsidence types, the foregoing data concerning frequency, intensity, etc., for Toledo and Mount Clemens can be taken as representative of the Detroit-Windsor area except in one special case. The exception is when there is advection over Lakes St. Clair or Erie directly to the Detroit-Windsor area. In the fall and early winter when the lakes are relatively warm, stability of the air will be decreased and in the spring and early summer, the lakes will be relatively cool, resulting in an increase in stability, both as related to the situation in Mount Clemens and Toledo. Data concerning frequency of nocturnal inversions at Mount Clemens and Toledo may be different than for Detroit in view of the differences found between the two sites studied. Similar differences have been reported in Toronto, Canada (52) where a 34°F temperature differential was found at two points only seven miles apart. The difference in frequency and characteristics of nocturnal inversions is dependent upon surface cooling which may vary widely from area to area. However, the seasonal trends for nocturnal inversions at Mount Clemens and Toledo probably would hold for the Detroit-Windsor area.

Table XI-8. Intensity of Inversions at Mount Clemens and Toledo
(In percent of inversions)

Type of Inversion[b]	Time	Season	Total No. observed	Lapse rate (degrees centigrade per 1000 meters)							
				-1.0 to 1.0	1.1 to 3.0	3.1 to 5.0	5.1 to 7.0	7.1 to 9.0	9.1 to 11.0	Greater than 11.0	Median lapse rate
Toledo (1/46-12/50)											
A	2200	Winter	171	7.0	8.2	14.0	11.7	7.6	9.9	41.6	9
A	2200	Spring	225	7.1	8.9	7.1	5.8	2.7	5.8	62.6	>11
A	2200	Summer	332	5.4	5.7	7.2	8.1	5.4	7.2	61.0	>11
A	2200	Fall	306	6.5	5.2	4.9	6.5	4.2	4.2	68.3	>11
A	2200	Annual	1034	6.4	6.7	7.6	7.9	5.0	6.8	59.6	>11
A[a]	1000	Annual	102	27.5	15.7	11.8	8.8	8.8	4.9	22.5	4
B[a]	2200	Annual	74	6.8	9.5	6.8	8.1	9.2	13.5	44.6	10
B[a]	1000	Annual	245	11.6	9.4	13.0	11.4	10.2	12.2	33.1	8
Mount Clemens (2/48-12/50)											
A	2200	Winter	48	14.6	12.5	12.5	8.3	8.3	8.3	35.4	8
A	2200	Spring	97	7.2	12.4	12.4	8.2	10.3	5.2	44.3	9
A	2200	Summer	151	15.9	11.9	12.6	6.6	7.9	6.6	38.4	8
A	2200	Fall	134	13.4	8.2	7.5	7.5	6.0	4.5	53.0	>11
A	2200	Annual	430	13.2	10.7	11.2	7.4	8.1	5.6	43.7	9
A[a]	1000	Annual	56	17.8	25.0	17.8	7.1	10.7	7.1	14.3	4
B[a]	2200	Annual	39	12.8	10.2	23.1	15.4	12.8	10.2	15.4	6
B[a]	1000	Annual	78	16.7	10.2	12.8	10.2	10.2	10.2	19.5	7

[a] Too few observations for reasonable seasonal breakdown.
[b] Type A - Inversion based at surface; Type B - inversion based above surface but below 1000 feet.

EFFECT OF VERTICAL MOTION OF AIR ON POLLUTION LEVELS

Measured Vertical Temperature Gradient and Pollution Levels

The effect of average atmospheric stability on suspended particulate pollution at 31 stations (as a whole) in Detroit was examined by analysis of four daily radiosonde observations taken at Selfridge Air Force Base, at Mount Clemens. Pollution and radiosonde measurements were made on 36 days during the period May 7 to June 17, 1951. Suspended particulate pollution was measured by use of high volume air samplers, taking 24 hour samples. Radiosoundings were taken daily at 0400, 1000, 1600 and 2200 EST. Each sounding was assumed to represent the state of the atmosphere for three hours preceeding and three hours succeeding balloon release time. Using this assumption, the number of surface inversions per day between the surface and 500 feet was taken to represent the length of time per day that air contaminants were confined to a relatively shallow layer of the atmosphere near the surface, and hence in a sense represent the average stability. The temperature difference in degrees C. between 500 feet and the surface was used as a criteria of low level stability, a positive value indicating that an inversion was present. The average suspended particulate pollution values were arranged in order of intensity and separated into four equal groups of nine each. The average pollution concentration, average number of inversions per day, and average temperature difference were all arranged according to the four classes (Table XI-11). It was concluded that average stability is a strong factor influencing average city-wide particulate pollution.

The temperature difference between that at

Table XI-9. Relative Frequency of Inversions with Various Wind Directions (a)
(In percent of time each wind direction occurred)

Time EST	Season	Wind Direction								
		N	NE	E	SE	S	SW	W	NW	Calm
						Mount Clemens				
2200	Winter	4	8	21	33	46	37	28	12	33
2200	Spring	34	65	50	69	74	57	20	19	67
2200	Summer	68	59	33	50	62	64	70	55	84
2200	Fall	62	56	50	71	58	61	46	39	74
2200	Annual	46	55	37	59	60	54	41	32	74
1000	Winter	11	5	0	25	30	11	2	0	20
1000	Spring	0	10	12	25	18	8	0	0	50
1000	Summer	2	7	2	2	3	2	2	0	9
1000	Fall	2	9	22	8	20	9	2	1	29
1000	Annual	3	9	6	14	16	7	2	1	20
						Toledo				
2200	Winter	15	20	38	73	72	48	24	13	83
2200	Spring	22	38	62	80	79	60	41	25	83
2200	Summer	41	54	65	86	86	83	70	61	93
2200	Fall	53	50	74	92	86	71	38	47	86
2200	Annual	32	42	61	86	81	65	39	33	88
1000	Winter	4	0	14	31	47	23	8	0	0
1000	Spring	0	2	1	8	17	2	1	1	0
1000	Summer	0	0	0	2	1	1	1	0	0
1000	Fall	6	5	2	11	13	4	4	3	29
1000	Annual	2	2	3	11	20	8	4	1	14

(a) Based on observations when there was no inversion or isothermal at the surface or in the first 1000 feet and when inversion or isothermal is based at surface.

Table XI-10. Average Wind Speeds with Various Lapse Rate Classifications
(In miles per hour)

Time EST	Season	Mount Clemens Lapse rate classification			Toledo Lapse rate classification		
		No inversion first 1000 ft.	Inversion based at surface	Inversion based at surface or in first 1000 ft.	No inversion first 1000 ft.	Inversion based at surface	Inversion based at surface or in first 1000 ft.
2200	Winter	11.9	10.5	10.8	13.0	10.3	10.3
2200	Spring	10.9	8.1	8.4	13.0	8.7	9.2
2200	Summer	8.0	6.0	6.2	8.5	5.6	5.6
2200	Fall	10.2	6.7	6.7	11.6	7.3	7.4
2200	Annual	10.4	7.2	7.4	12.0	7.6	7.8
1000	Winter	12.3	11.4	11.9	14.9	11.2	12.3
1000	Spring	12.4	12.7	11.8	14.4	13.2	12.1
1000	Summer	9.3	7.1	7.6	9.9	13.5	9.5
1000	Fall	11.4	8.8	9.2	11.7	10.9	10.6
1000	Annual	11.2	10.4	10.5	12.6	11.5	11.5

Table XI-11. Atmospheric Stability and Suspended Particulate Pollution

Range of pollution concentrations (ug/cu.m.)	Average pollution concentration (ug/cu.m.)	Average Temperature difference (500 feet minus surface) in °C	Average No. inversions per day
446-306	348	+ 0.12	1.9
306-224	252	- 0.34	1.2
223-173	204	- 0.57	1.2
172- 98	132	- 0.80	0.9

the earth's surface and at the elevation above ground where atmospheric pressure was 850 millibars (normal pressure at the surface is 1013 millibars) was tested for relationship with suspended particulate pollution. The average daily temperature difference at the two elevations was obtained from the four daily radiosoundings at Selfridge Air Force Base during the period August 24 to September 18, 1952. Particulate Pollution was measured seven days a week at two stations in Windsor and at three stations in Detroit. At six other stations in Detroit, samples were taken four days a week. All were 24-hour samples collected with high volume filters. The data indicated a close relationship between suspended particulate pollution and average daily vertical temperature profiles with pollution levels being relatively high on those days when the decrease of temperature with height was relatively low (Figure XI-14).

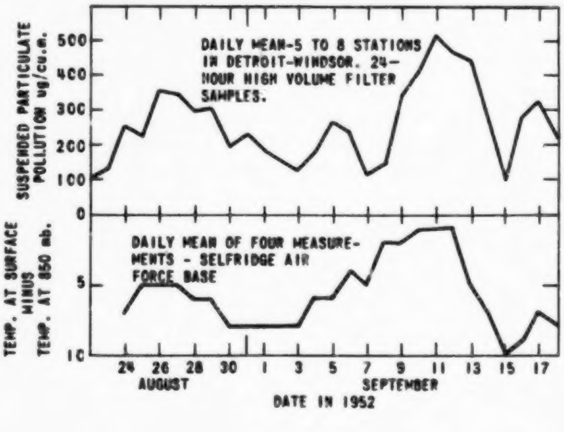


Figure XI-14. Relationship Between Suspended Particulate Pollution and Vertical Temperature Gradient.

Variation of Pollution Levels with Elevation Above Ground

Since the vertical motion of air is not uniform during different time periods, the relationship between pollution concentrations at various elevations above ground will change from time to time. The location and elevation above ground of pollution discharge points and wind speed, direction, and turbulence will also influence vertical distribution of pollution.

Two Thomas Autometers were operated in the Majestic Building in downtown Detroit during March 1953. One was in the basement with a sampling probe extended outside the building at about two feet above ground. The other was on the tenth floor at about 125 feet above ground.

The diurnal variation of half hourly average concentrations of sulfur dioxide at the two elevations are similar but concentrations at 125 feet above ground averaged 0.016 ppm (27 percent) higher than those at ground level (Figure XI-15). This suggests that sulfur dioxide emissions are greater near the 125 foot level than near ground level. Larger values of the vertical pollution gradient occur during the night hours when thermal turbulence is suppressed and lower values occur during the daytime when solar heating of the earth causes greater thermal turbulence.

Sulfur dioxide concentrations at the 125 foot level begin to decrease within an [illegible] sunrise while concentrations at gro[illegible] continue to rise. This is due to the increasing vertical mixing of the lower concentrations at ground level with the higher concentrations at 125 feet. After the sun has been up for about two hours (0830), thermal turbulence is further strengthened and concentrations at both elevations are decreasing due to increased mixing with less polluted air from elevations above 125 feet.

During November 1953, two high volume air samplers were operated simultaneously at the Majestic Building, with one located six feet above ground and the other at 125 feet above ground. Each sample was taken over a 24-hour period using fiberglass filter media. There was no consistent relationship between concentrations of suspended particulate matter at the two elevations although the average at ground level was 350 micrograms per cubic meter as compared to 338 at 125 feet above ground (Figure XI-16). Statistical tests indicate greater than a 50 percent chance probability of a difference of this magnitude being found. The results indicate that differences in rate of pollution emission at the two levels, vertical mixing rates, wind direction and rate of particle fall act jointly in such a manner that particulate pollution levels in the lowest 125 feet above ground are essentially uniform at this location on an average basis. However, large differences in pollution levels at the two elevations do occur on particular days (Figure XI-16). The same general findings were made with regard to the organic fraction of the particulate matter as for total particulate matter.

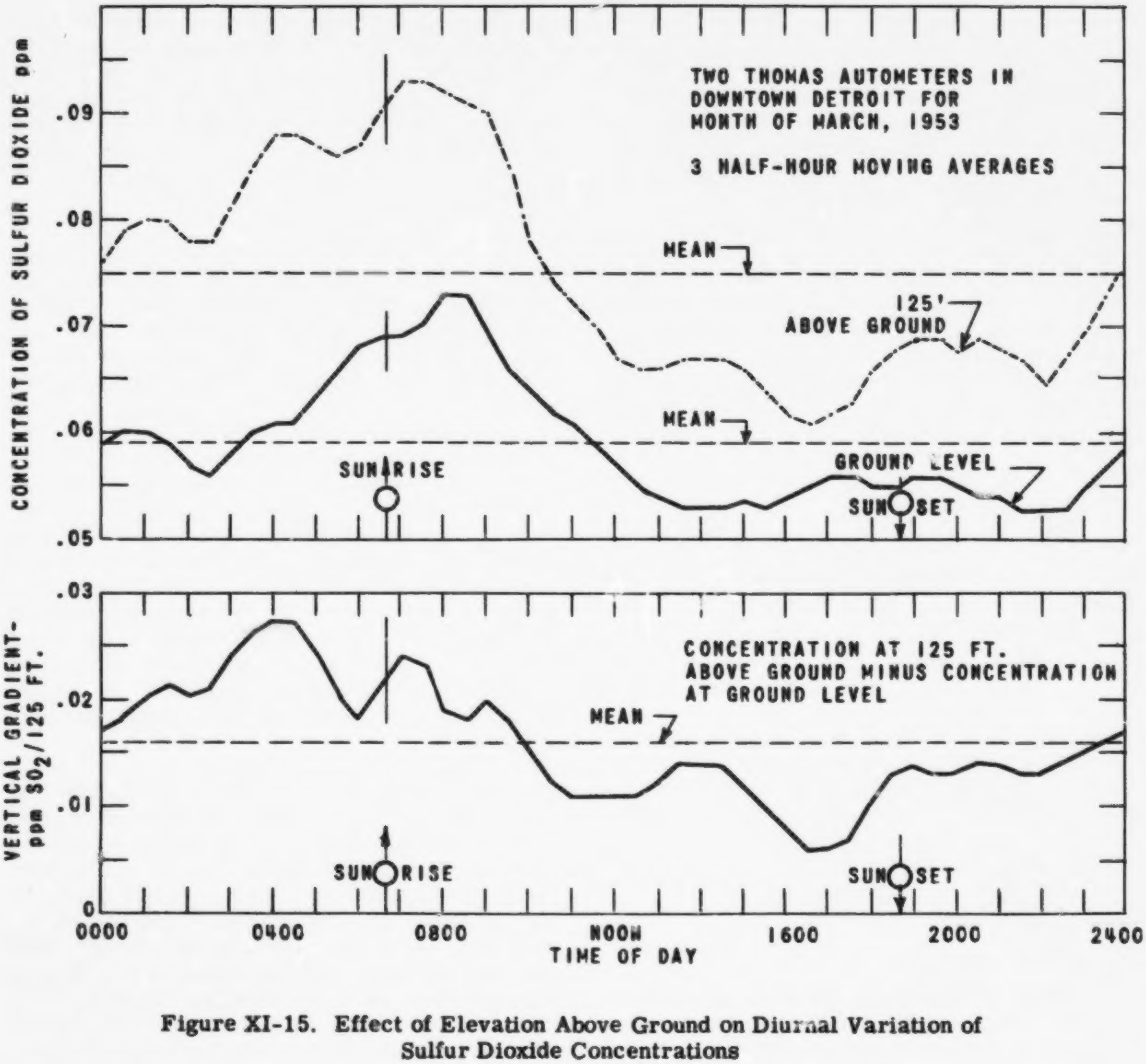


Figure XI-15. Effect of Elevation Above Ground on Diurnal Variation of Sulfur Dioxide Concentrations

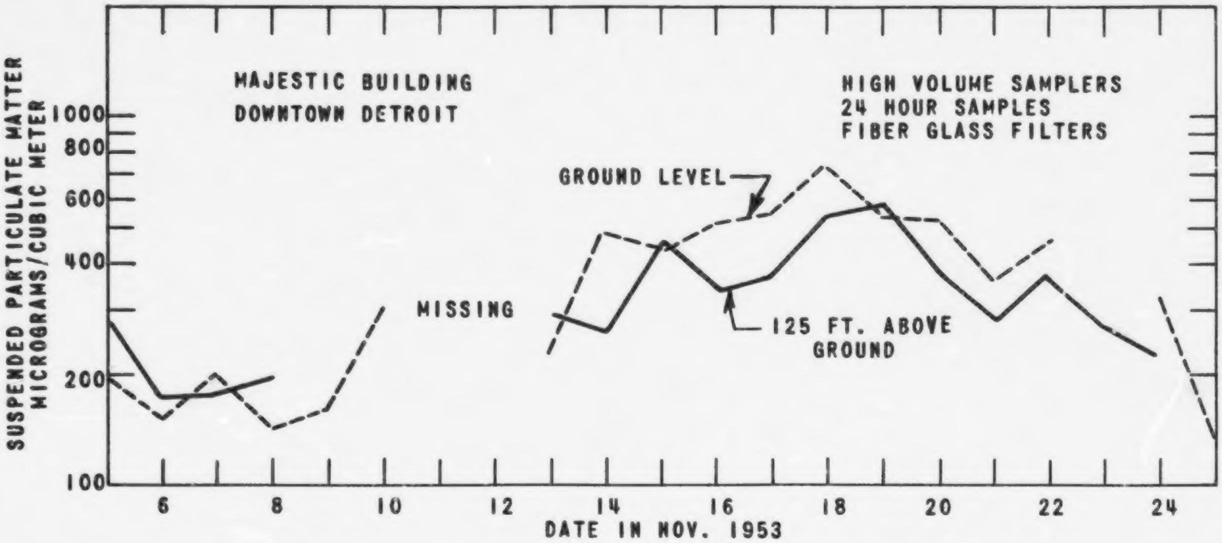


Figure XI-16. Concentration of Particulate Matter at Ground and 125 Feet Above Ground

Diurnal Variation of Pollution Levels

Vertical temperature gradient and its resulting effect on the vertical motion of air have a strong influence on the diurnal variation of pollution levels. Frequently occurring nocturnal inversions, setting in after sunset and breaking shortly after sunrise, are responsible for a considerable portion of the usual diurnal pattern of pollution levels which exhibit maximum pollution near the time of sunrise and relatively high levels in the evening and night (Figure XI-17). The similarity of the shape of the curves in this figure and those in Figure XI-5 for type 1 inversions (inversion in all layers from the surface to 870 feet above ground) is particularly noteworthy. The suspended particulate matter curve in Figure XI-17 appears to be shifted about one hour earlier (to the left) of the sulfur dioxide curve. This is probably caused by the difference in times of year represented by the two curves with the suspended particulate curve representing a time period of relatively greater number of early sunrises than the year-round period of the sulfur dioxide curve.

WIND SPEED AND DIRECTION

Wind speed will partly control the rate at which a polluted area is ventilated by relatively clean air (Figure XI-18). In the broadscale pattern, wind speeds at 2000 feet or higher are dependent upon the nature of the pressure system as indicated by the spacing of isobars on synoptic charts. Strong winds occur with closely spaced isobars which indicate rapid pressure change over short distances. Because of friction, the surface wind will be lower in speed. However, when the air is unstable, the air within the friction layer becomes thoroughly stirred and the surface winds may be closer in magnitude to the winds at the 2000-foot level. Since daytime heating from the sun generally causes thermally unstable air, there is a diurnal variation in the strength of the surface wind. When the broad-scale wind pattern is strong, local wind effects become masked and unimportant. Under such conditions there is rapid ventilation of a city. If, for example, a 20-mph. wind is blowing across a city 10 miles in diameter, there will be a complete change of air every half hour.

The strength of local wind components (Figure XI-19) will depend upon the magnitude of the temperature difference between land and lake, or city and country. When the broad-scale wind pattern becomes light for 6 hours or longer, the local wind effects can be important. However, there will be no true ventilation of the city because the local winds form part of a closed system. For example, a lake breeze will extend only a few miles inland; there will be an overturning of air, but there is no way for most of the pollution to escape from the system.

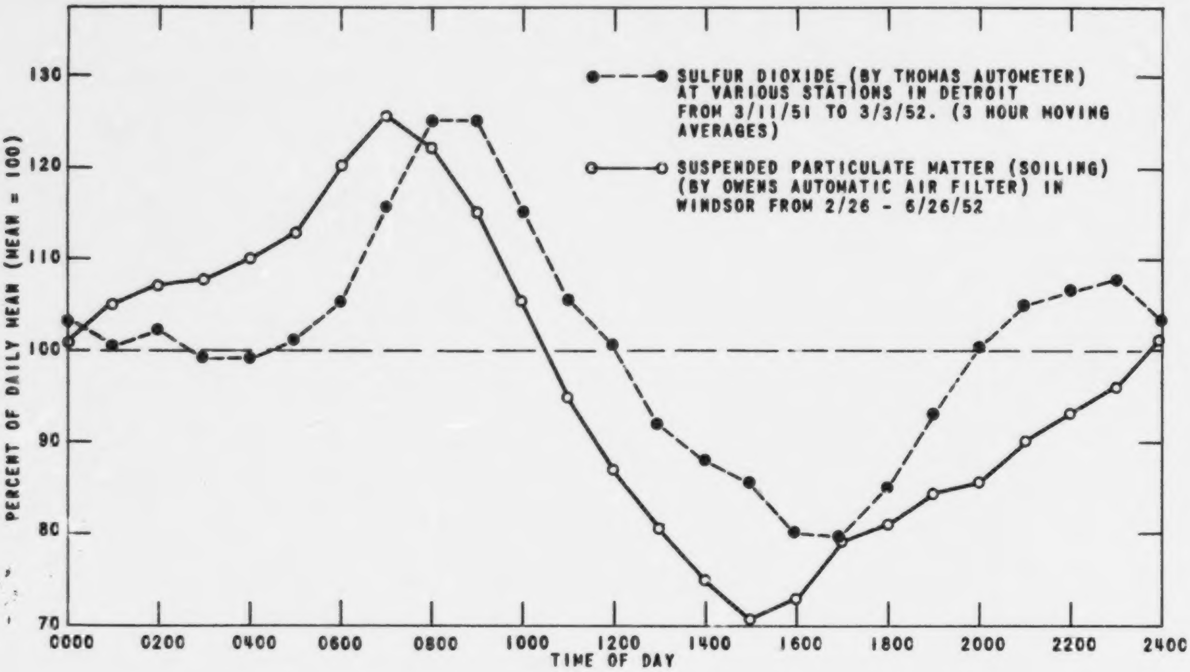


Figure XI-17. Diurnal Variation of Relative Pollution Levels

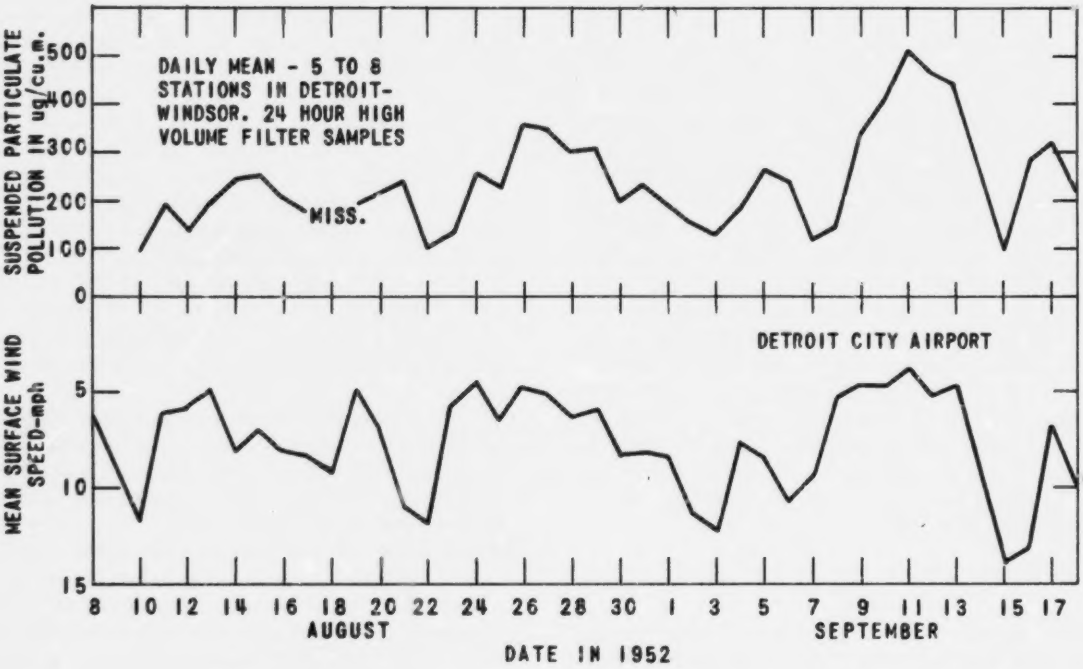
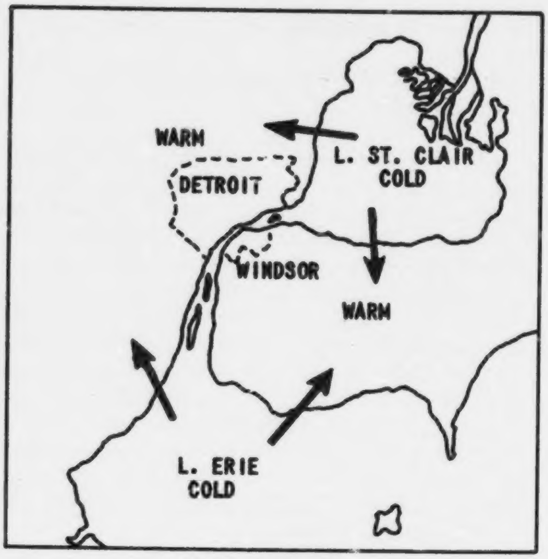
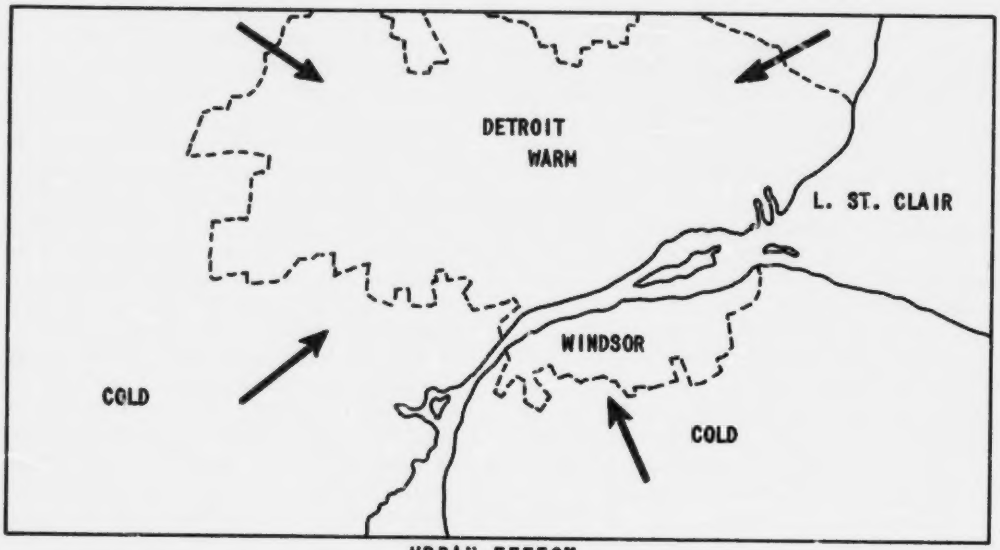


Figure XI-18. Effect of Wind Speed on Suspended Particulate Pollution


WARM
L. ST. CLAIR
COLD
DETROIT
WINDSOR
WARM
L. ERIE
COLD
COLD
L. ST. CLAIR
WARM
DETROIT
WINDSOR
COLD
L. ERIE
WARM

LAKE BREEZE LAND BREEZE


DETROIT
WARM
L. ST. CLAIR
WINDSOR
COLD
COLD

URBAN EFFECT

ARROWS DENOTE WIND DIRECTION

Figure XI-19. Examples of Local Winds

In the broad-scale pattern, in the absence of special local effects, wind direction at 2000 feet above ground is governed by pressure systems as indicated by isobars on synoptic charts. Because of friction, the surface wind is usually deflected 15 to 30 degrees in a clockwise sense, the exact deflection being dependent upon the roughness of the ground, wind speed, stability, etc.

There are several local factors which modify broad-scale wind direction. Whenever there is a temperature difference between two adjacent areas and whenever the broad-scale flow becomes light, a component of wind can often be detected blowing from the cold area to the warm. Two examples of this are the lake-land breeze and the urban-rural breeze (Figure XI-19). The resultant circulations can be complex with changes in wind direction, both vertically and horizontally. A photograph taken at the Brookhaven meteorological tower installation (111) shows smoke emitted at 3 elevations above ground moving in 3 different directions. Since sources of emission in a city are distributed vertically from street level to the top of the highest stack and horizontally across the length and breadth of the city, the drift of pollutants becomes very difficult to describe.

Wind direction need not exert the same influence on all locations in the Detroit-Windsor area because of the relationship between pollution source location and pollution concentration. If, in the area-wide aspect, concentration of a certain pollutant is strongly influenced by wind direction, the variation in pollution levels from time to time and from place to place will not be uniform. If other weather factors exert a stronger influence than wind directions, pollution levels would vary in a more uniform manner throughout the area. Sulfur dioxide pollution data obtained simultaneously over a long period at two stations in Detroit, three in Windsor and one each at Harrow and La Salle were examined. The most centrally located sampling station was used as a reference and coefficients of correlation between pollution levels at each of the other stations and the reference station were computed. The sulfur dioxide pollution levels did not vary in a uniform fashion except at two stations in Detroit during the winter and spring seasons, indicating that sulfur dioxide levels in the atmosphere at a point are influenced more by location of sources around the point and wind direction than by other weather factors.

The concentration of suspended particulate matter measured simultaneously for a long period at four stations in Detroit, two in Windsor and one in Harrow were examined in a similar manner. Suspended particulate pollution levels varied in a uniform manner at all stations. When pollution was relatively low or high at one station, the same was generally true for all stations. The degree of correlation was statistically significant at the most rigorous one percent level. Therefore, it was concluded that suspended particulate pollution levels are influenced to a greater extent by other weather factors than by location of sources of particulate matter around the sampling station and wind direction.

TRANSBOUNDARY MOVEMENT OF POLLUTION

During the period February 8 to March 11, 1954, a study of the concentration of suspended particulate pollution was carried out at 13 points along the Detroit River. The stations were located in pairs, one on either side of the river, and both as close to the water's edge as possible. Six such pairs were operated from near the southern end of Grosse Ile to the eastern end of Belle Isle, plus a single station on the Canadian side of the river almost directly across from Woodward Avenue in Detroit. The study was designed to provide evidence of transboundary flow of pollution. It was deliberately carried out at a time when there was very little vessel traffic on the river.

Pollution levels were taken as the total weight of particulate matter collected each 24-hour period by high volume air filters. The prevailing wind direction for each day was taken from observations made at the Windsor airport after finding that wind directions measured simultaneously at three points along the Detroit River indicated general agreement with those at the airport. The measured pollution values were treated by use of the weather index (described later in this chapter) to make the final pollution values assigned to the prevailing wind direction each day more truly represent wind direction influence rather than other weather influences. Pollution windroses were drawn (Figure XI-20). Preliminary computations indicated that use of the weather index procedure was statistically valid for the period of the transboundary study. There was no day during the study when the prevailing wind was from the southeast. A value was assigned to this wind direction using smoothing techniques for the values on the 5 days with east winds and the 8 days with south winds. Only the net transboundary effect during the study was considered although winds do not blow with equal frequency in all directions.

The conclusions reached were:

a. At the southern end of Grosse Ile there is a slightly greater transboundary flow from Canada to the United States than in the other direction. However, levels of pollution involved are low--typical of those experienced in rural areas;

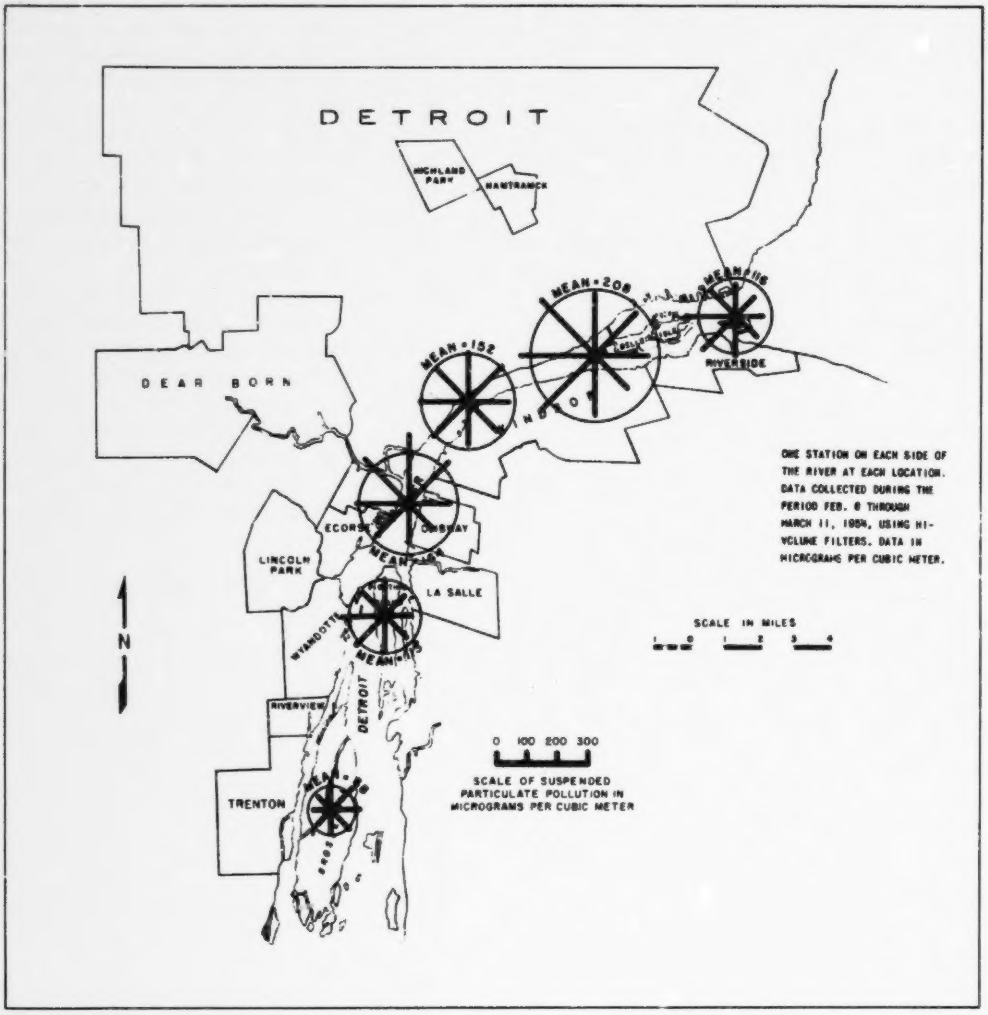

DETROIT
HIGHLAND PARK
HAMTRAMCK
DEARBORN
MEAN = 152
MEAN = 208
MEAN = 115
WINDSOR
RIVERSIDE
ECORSE
OJIBWAY
LINCOLN PARK
LA SALLE
WYANDOTTE
RIVERVIEW
DETROIT
TRENTON
N
ONE STATION ON EACH SIDE OF THE RIVER AT EACH LOCATION. DATA COLLECTED DURING THE PERIOD FEB. 8 THROUGH MARCH 11, 1964, USING HI-VOLUME FILTERS. DATA IN MICROGRAMS PER CUBIC METER.
SCALE IN MILES
1 0 1 2 3 4
0 100 200 300
SCALE OF SUSPENDED PARTICULATE POLLUTION IN MICROGRAMS PER CUBIC METER

Figure XI-20. Transboundary Flow of Suspended Particulate Pollution

b. In the vicinity of Wyandotte and LaSalle, there is a slightly greater transboundary flow of pollution from the United States to Canada than in the opposite direction. The levels of pollution involved are only slightly higher than those found in rural areas;

c. In the vicinity of River Rouge and Ojibway, there is evidence of a considerable transboundary flow of pollution from the United States to Canada. At this pair of stations it was noted that when winds were west or northwest, the effluents from tall stacks on the American side passed overhead at the American station but reached the Canadian station. The explanation is that the pollution remained aloft on the American side but diffused to ground level by the time it reached the Canadian side of the river;

d. In the vicinity of the Ambassador Bridge there is evidence of a slightly greater flow of pollution from the United States to Canada than in the other direction.

e. At the other sampling points there is no clear evidence of any differential trans-boundary flow of pollution.

INFLUENCE OF MAJOR POLLUTION SOURCES AND WEATHER FACTORS ON POLLUTION AT ONE STATION

In cases where one or more major pollution sources are situated near a certain location, pollution levels are often influenced by weather factors in a different fashion than pollution levels for a generalized area such as Detroit-Windsor. One such situation was investigated in the southern part of the study area involving the Peter and Chappell Streets Air Sampling Station, a large coal-steam electricity generating plant and the major pollution sources in the Ecorse, Zug Island, and River Rouge areas (Figure XI-21).

At the Peter and Chappell Streets station, a Thomas Autometer provided continuous measurements of sulfur dioxide and a Bendix-Friez Aerovane provided measurements of hourly wind speed and direction at an elevation of 20 feet above ground. Data for the period October 16, 1953 to February 28, 1954 were used in this study. Wind speed and direction data were recorded for every hour, starting on the hour. Integrated sulfur dioxide data were available for each 25 to 30 minute period, not necessarily on the hour or half hour. Therefore, all 30 minute (approx.) sulfur dioxide values falling entirely within one hour (e.g. beginning 0915 and ending 0945) were assigned to the appropriate data for wind speed and direction (e.g. the hour ending 1000). Values beginning in one hour (e.g. 0945) and ending in another (e.g. 1015) were used if the wind direction in both hours was the same. If not, the hour was not used. In case two hours

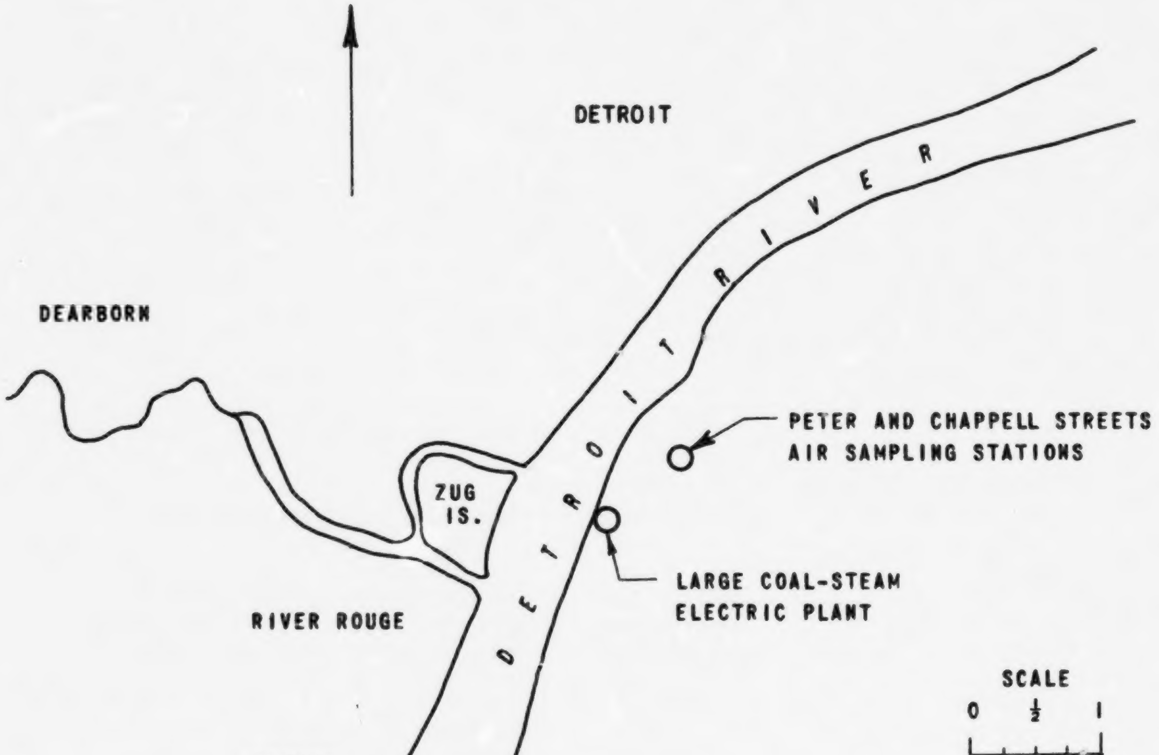

DETROIT
DEARBORN
ZUG IS.
DETROIT RIVER
PETER AND CHAPPELL STREETS AIR SAMPLING STATIONS
LARGE COAL-STEAM ELECTRIC PLANT
RIVER ROUGE
ECORSE
SCALE
0
½
1
MILES

Figure XI-21. Location Map for a Major Pollution Source Evaluation

with a divided sulfur dioxide value were used, the mean wind speed for the two hours was used with the corresponding sulfur dioxide value. A log of 4530 observations of coincident wind direction and pollution values resulted, from which a sulfur dioxide concentration frequency table was prepared (Table XI-12). The log included wind speed data for 1087 occurrences of southwest winds. Of those, 781 hours were preceeded by two or more hours of southwest wind and followed by one or more hours of southwest wind. These 781 hours were used to prepare diurnal pollution curves for three wind speed groups (Figure XI-22). This selection was made to insure that the atmospheric concentrations of sulfur dioxide attributed to southwest winds were the best possible observations. Average operating rates at the coal-steam electric plant (for the hours during which the 10, 11 and 12 mph southwest winds used in the diurnal pollution variation curve occurred) were added to Figure XI-22.

The lowest concentrations of sulfur dioxide at the sampling station occur with east and southeast winds (Table XI-12 and Figure XI-21) and are a reflection of the rural nature of the upwind area in those directions. The moderate concentrations accompanying west and northwest winds are a reflection of pollution arising in Detroit and the Dearborn area. Low concentrations with northeast winds indicate pollution coming from Windsor. Concentrations of sulfur dioxide with north winds are unexplainably low. The city of Detroit is upwind to the north which would lead one to expect more sulfur dioxide than was found.

On the basis of sources of sulfur dioxide pollution existing south of the sampling station, it would appear that low concentrations are to be expected. However, the data (Table XI-12) show eight percent of the measurements were over 0.10 ppm. This apparent discrepancy is explained by the differences in wind direction which often exist near ground level and at higher elevations. In this case, wind direction was measured at 20 feet above ground but the stacks at the steam electric plant are 220 feet high. The wind direction tends to shift in a clockwise sense with increasing height as a result of frictional drag of the earth. Thus it may happen that southwest winds at stack height, transporting stack discharges toward the sampling site, occur with south winds at 20 feet above ground. A reasonable value for the angle between the wind at the surface and at 300 feet is 20 degrees but with light to moderate winds and the influence of the north-south course of the river, the wind might be turned as much as 35 degrees. The 300 feet is estimated effective stack height, adding 80 feet to the 220 foot stack for the bouyancy of hot stack gases and their velocity. There will also be a fanning of the emissions as they spread downwind from the stack. It was concluded that emissions from the steam electric plant could reach the sampling site and were responsible for at least some of the high sulfur dioxide concentrations recorded with south

Table XI-12. Relative Frequency of Occurrence of Sulfur Dioxide Concentrations at Peter and Chappell Streets by Wind Directions

(10/16/53 to 2/28/54--half hourly average Thomas Autometer readings)

	Percent frequency of occurrence at concentration (in ppm) listed							Total occurrences	Median concentration in ppm
	0.00	0.01 to 0.05	0.06 to 0.10	0.11 to 0.20	0.21 to 0.30	0.31 to 0.40	Over 0.40		
N	51	29	15	5	0	0	0	339	0.00
NE	45	39	12	3	1	0	0	222	0.01
E	63	32	4	1	0	0	0	326	0.00
SE	89	10	0.3	0.3	0	0	0	323	0.00
S	38	41	13	6	1	0.5	0.5	861	0.02
SW	5	28	24	20	12	7	4	1087	0.09
W	10	50	31	8	1	0.1	0	1048	0.04
NW	10	51	23	13	3	0	0	322	0.04

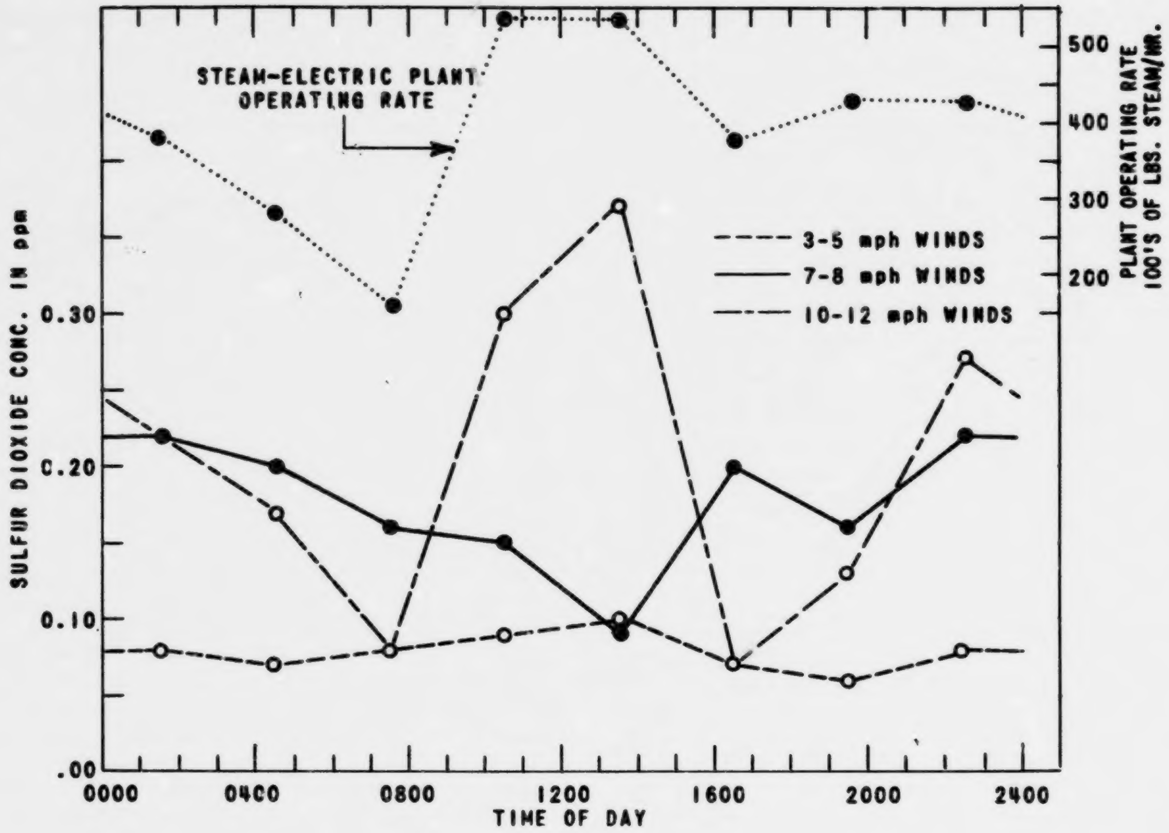


Figure XI-22. Diurnal Variation of Sulfur Dioxide Levels at Peter and Chappell Streets with Southwest Winds, by Wind Speed Classes

winds at ground level. Other high concentrations measured with south winds may have been due to a similar dispersion pattern acting on emissions arising in the Ecorse-River Rouge area.

Diurnal variations in sulfur dioxide with southwest winds (Figure XI-22) are the resultant of a complex relationship involving wind speed and direction, vertical stability, mechanical wind turbulence, and pollution emission rates at the steam electric plant and establishments in the Ecorse-River Rouge area where there are many tall and short stacks emitting sulfur dioxide. The effluents from tall stacks may remain aloft almost indefinitely when an inversion exists. Increased turbulence may lead to increased concentrations of pollutants at the ground from a particular source due to more rapid and concentrated transport of the stack effluent to ground level. Further, as wind speed increases, the angle between the axis of a stack plume and the horizontal decreases. At a critically high wind speed, the phenomenon of downwash occurs resulting in remarkably high pollution levels at the ground. At wind speeds of three to five mph, stack plumes will be sloping definitely upward and there will be little turbulence of mechanical origin. The combination probably causes the steam plant plume to pass over the sampling site. The relatively low concentrations of sulfur dioxide recorded probably originated in the Ecorse-River Rouge area and were reduced in intensity by the time they arrived at the sampling site. However, a slight peak in concentration occurred at about 1400 EST, presumably the time of maximum thermal turbulence, when stack plumes may be bought to the ground in relatively low dilutions. With wind speeds of seven to eight mph, stack plumes will be sloping only slightly upwards and there will be sufficient mechanical turbulence to cause some stack plumes to reach the ground in concentrated form on many occasions, resulting in the generally higher concentrations at seven to eight mph wind speeds than at three to five mph. However, emissions from the nearby steam plant will probably not reach the ground at the sampling sites in large concentrations on many occasions. Most of the pollution at the sampling site is due to sources in the River Rouge--Ecorse area with wind speeds of seven and eight mph. The maximum-minimum pattern cannot be explained with available information. At wind speeds of 10 to 12 mph, it appears that effluents from the nearby steam plant reach the ground in relatively undiluted form because of great vertical turbulent mixing and possibly down-wash. The shape of the diurnal pollution level curve for wind speeds of 10 to 12 mph is very similar to the curve for operating rates at the steam electric plant (Figure XI-22) indicating that sulfur dioxide from the plant was reaching the sampling station.

PRECIPITATION

The effect of precipitation on particulate and gaseous matter in the atmosphere has not yet been adequately described. Pollution can be collected by precipitation prior to descent (rain-out) or during its descent (wash-out).(111) Presumably, the amount of cleansing of the air will depend upon the size of the droplets or snowflakes, the rate of fall, and the duration of precipitation. Precipitation transfers pollution from the sky to the ground. For certain types of pollution such as atomic wastes, precipitation can therefore increase ground-level hazards. Meteorological conditions which produce precipitation are very often accompanied by frontal or thermal vertical turbulence and hence good dispersion of pollutants. Therefore, lower pollution levels may accompany precipitation regardless of whether the rain-out or wash-out process was responsible for lowering pollution levels. Precipitation also reduces the amount of wind-blown surface dust by wetting it and thereby indirectly brings about a reduction in particulate pollution levels. Only the combined effect of these factors can be determined by directly comparing pollution levels with precipitation frequency, quantity and duration.

A study was made of the relationship between suspended particulate pollution levels and precipitation during the period May 7 to June 17, 1951. High volume air filters at 31 stations in Detroit provided 24-hour data on suspended particulate pollution and hourly records of precipitation were obtained from the U.S. Weather Bureau Station at Detroit City Airport. When precipitation occurred, minimum particulate pollution concentrations were usually recorded (Figure XI-23). However, when the quantity of rainfall was compared with average particulate pollution, no correlation was found since both high and low concentrations of pollution were observed with small amounts of rainfall. Rain showers, rather than steady rain were most often reported for days when atmospheric pollution was low.

OTHER METEOROLOGICAL PARAMETERS

The passage of a cold front through the Detroit-Windsor area has the effect of reducing pollution levels during the time following movement of the front through the area. This is caused by a number of factors including strong surface winds ahead of and behind the front, the unstable nature of inflowing cold air, and common occurrence of precipitation with the frontal passage. During the period August 7 to September 19, 1952, nine cold fronts passed through the Detroit-Windsor area. Suspended particulate pollution at nine stations in Detroit averaged about 60 percent lower for the 24-hour periods following passage of the cold fronts than for the 24-hour periods preceeding passage of the fronts.

Temperature anomaly, or the difference between the temperature on a particular day and the long-time average temperature for that day, is related to pollution levels although temperature by itself exerts no direct influence on pollution levels, except for government of space heating requirements, which in turn bear on pollutant emission rates. However, temperatures below average are usually accompanied by relatively low pollution levels because the incoming cool air is heated by the surface, resulting in turbulent mixing and good dispersion of pollutants. Temperatures above average are usually accompanied by relatively high pollution levels because a warm air mass is advancing over cooler ground which cools the layer of air nearest the surface, resulting in stable conditions with little turbulence and poor dispersion of pollutants. Simultaneous measurements of suspended particulate pollution at eight stations in the Detroit-Windsor area and the daily tempera-

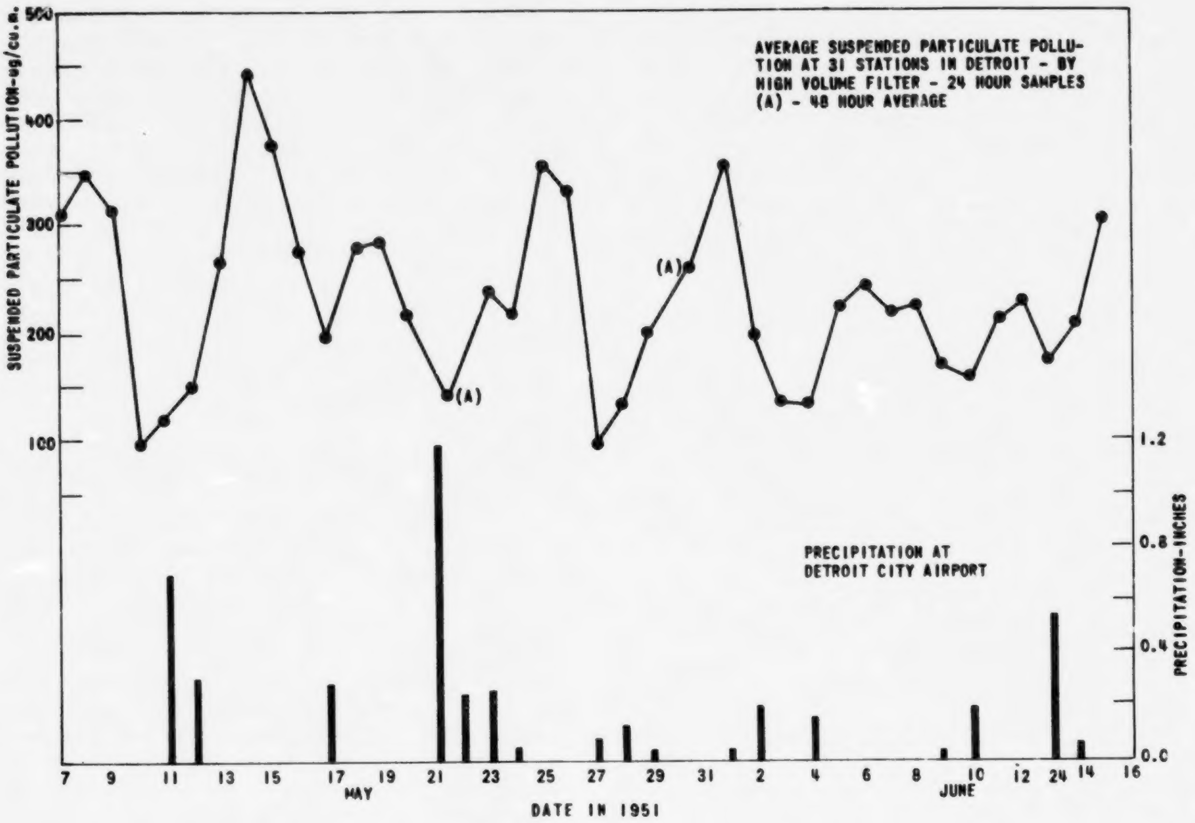


Figure XI-23. Suspended Particulate Pollution and Precipitation (May 7 to June 17, 1951)

ture anomaly during the period August 7 to September 19, 1952 demonstrated the relationship between these two variables (Figure XI-24).

Barometric pressure is not related directly to pollution levels, although pressure patterns and the associated weather patterns do affect pollutant concentrations. Kleinsasser and Wanta (42) report that "The polar anticyclone undergoing transformation to the deep warm-type anticyclone appears to be the meteorological model most likely to produce the prolonged stagnant conditions required for abnormally large waste gas concentrations." The difficulty, of course, is to define specific limits for the required pressure distribution or distributions. This involves the broad-scale study of pollution meteorology, as opposed to the micrometeorological approach.

Clouds are an indication of the stability of the air; cumulus clouds are associated with instability, while the stratus-type are a sign of stability. There is often an inversion at the base or top of stratus-type clouds. Cloud cover indirectly influences stability by its effect on the amount of solar heating of the ground possible with various proportions of cloud cover.

Although vertical and horizontal variations of humidity may be a factor in urban pollution studies, no useful relationships have yet been found.

The state of the ground is related to atmospheric pollution. Wind lifts dust, sand and pollen from the ground into the lowest layers of the atmosphere. When the ground is damp or snow-covered, the effect will be minimized. The degree of wind-blown particulate pollution will also be influenced by particle size and weight, wind speed, and stability.

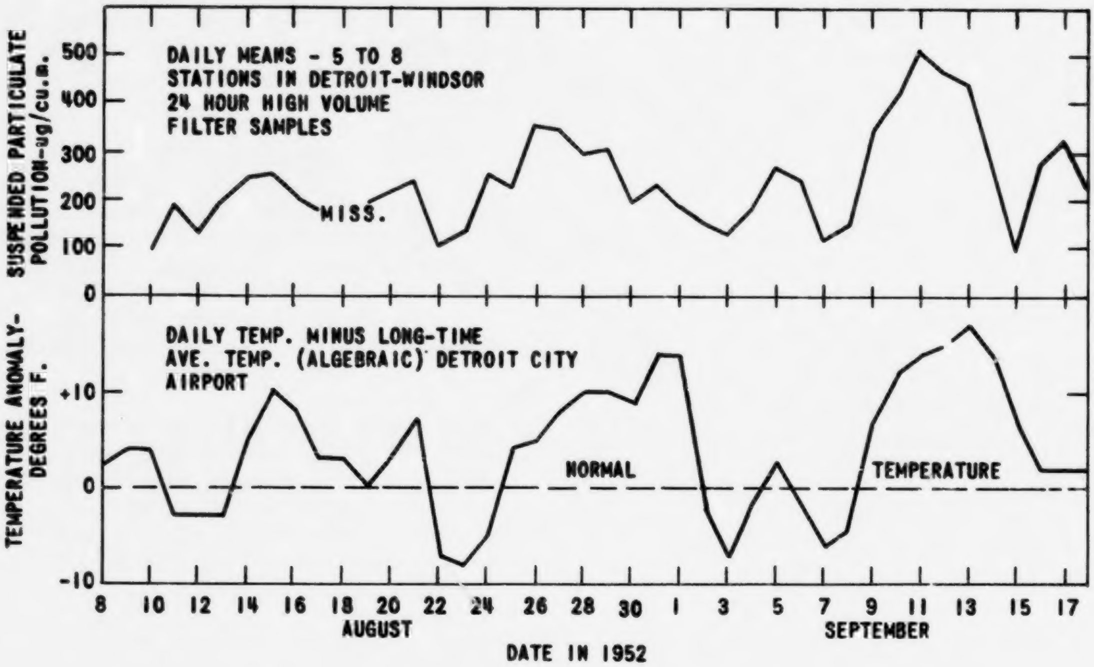


Figure XI-24. Suspended Particulate Pollution and Temperature Anomaly

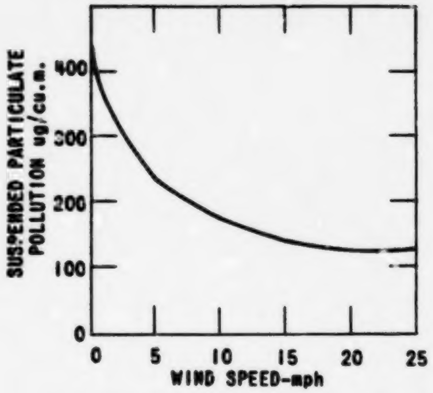
MULTIPLE CORRELATION OF POLLUTION WITH WEATHER FACTORS

A graphic multiple regression technique(5) was developed which makes it possible to estimate suspended particulate pollution levels from observations of wind speed, duration of precipitation and a thermal factor consisting of the algebraic sum of the daily temperature anomaly and the 24-hour temperature change (a measure of the stability of the air). The basic equation was developed from data obtained by use of 20 high volume air samplers in Detroit-Windsor during the period August 7 to September 17, 1952 and weather data obtained from records at Windsor Airport. The normal daily temperature used was the 79-year Detroit city record. The equation of best estimate for particulate pollution levels is:

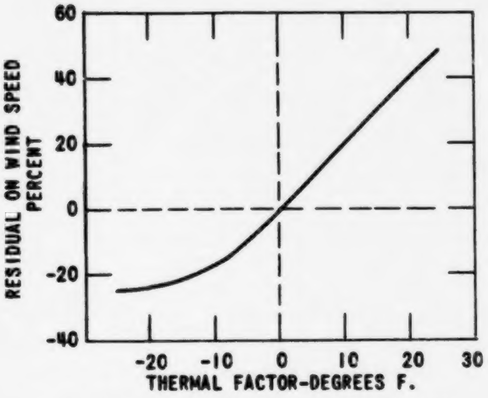
$$X_1^c = X_1^i \frac{(100 + R_1^i + R_2^i)}{100}$$

X_1^c is the estimate of pollution; X_1^i is the regression value of pollution, based on mean wind speed obtainable from Figure XI-25(A); R_1^i is the regression value of the relative residual from regression on wind speed, based on the thermal factor obtainable from Figure XI-25(B); and R_2^i is the regression value of the residual from regression on the thermal factor, based on rainfall obtainable from Figure XI-25(C). The coefficient of multiple correlation, obtained by correlating estimates of particulate pollution from the equation with observed values of particulate pollution, was 0.92. Although no rigorous claims can be made about significance of results where graphic methods have been used, the large correlation coefficient indicates that most of the variation in pollution levels was accounted for.

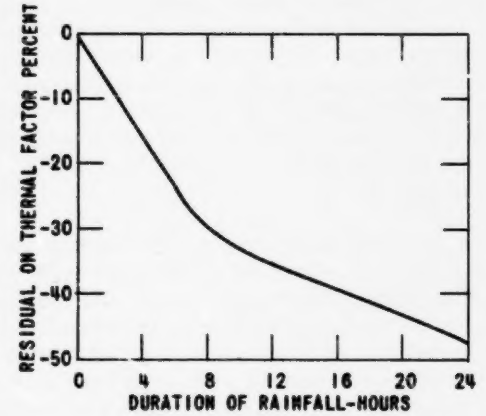
The analysis was then applied to four independent sets of meteorological and particulate pollution data. However, since the original equation of best estimate was developed for a certain season of the year using data from 20 air sampling stations, it was necessary to consider a further regression formula which would compensate for: different rates of pollution emission in other seasons; difference in pollution levels indicated by the original 20 station network as compared to the six station network operating at the time the four independent sets



A. NET REGRESSION OF PARTICULATE POLLUTION ON SURFACE WIND SPEED



B. NET REGRESSION OF PARTICULATE POLLUTION ON THERMAL FACTOR



C. NET REGRESSION OF PARTICULATE POLLUTION ON DURATION OF RAINFALL

Figure XI-25. Regression Curves for Estimation of Particulate Pollution from Weather Factors.

of data were collected; and variation in degree of weather influence on pollution levels in different seasons. The further regression formula was:

$$X_1 = a X_1^c + b$$

In this equation, X_1 is the measured particulate pollution, X_1^c is the estimate of pollution, and a and b are constants. The results of the analysis of the 4 sets of independent data and the original set of data are given in Table XI-13, along with the equation of best estimate established for each group of observations.

The correlation coefficients for the independent data are less than for the original sample. They are, however, large enough to suggest that the analysis may be applied profitably, although no rigorous statements of significance are possible. It would appear from these coefficients that weather elements influence pollution levels less in winter and spring. However, other weather factors are involved that are not considered in the regression formula. For instance, snow cover or surface moisture may alter reentrainment in winter and spring, while temperature and wind induce large changes in emissions due to use of fuel throughout the heating season.

WEATHER INDEX OF POLLUTION

A weather index of pollution was developed which makes it possible to express the total effect of wind speed, the thermal factor, and precipitation on pollution levels in absolute terms. The index can be used to estimate the normal pollution level at a location on the basis of a few pollution measurements made over a short period of time and measurements of the three weather factors as they prevailed at the time the pollution was measured. It may also be used to define the influence of wind direction at a location under normal conditions by accounting for the effects of the other three weather factors.

The weather index was derived by converting the suspended particulate pollution values in Figure XI-25(A) to absolute values, using the long-term area-wide average of 170 micrograms per cubic meter as 100 percent. The mean wind speed in Detroit is 10.6 miles per hour to which the 170 micrograms per cubic meter average particulate pollution value was assigned. Particulate pollution at all other wind

Table XI-13. Statistical Quantities for the Original Multiple Correlation for Four Independent Sets of Data

Period analyzed	No. days used	Correlation coefficient	Equation of best estimate	
August 7 to September 17, 1952	40	0.92	$X_1 = X_1^c$	(Orig. data)
September, October, November, 1953	41	0.79	$X_1 = 1.03X_1^c + 25$	Independent data
December 1953 to January, February 1954 . .	44	0.57	$X_1 = 0.64X_1^c + 48$	
March, April, May, 1954	42	0.41	$X_1 = 0.65X_1^c + 108$	
June, July, August, 1954	51	0.73	$X_1 = 1.04X_1^c - 22$	

speeds were then computed as a percentage of that occurring at the mean wind speed and on the basis of the curve in Figure XI-25(A). Absolute values used in accounting for the thermal factor and precipitation were obtained directly from Figures XI-25(B) and (C). All absolute values were tabulated (Table XI-14). The formula used for computing the weather index is:

$$I = F_v\,(100 + F_t + F_r)\,/100$$

in which I is the weather index, F_v is the wind speed factor, F_t is the thermal factor and F_r is the precipitation factor.

The use of the index to estimate normal pollution levels from observed particulate pollution and weather factors is illustrated as follows: on a particular day, mean wind speed was 5 mph, normal temperature for the day was 28°F but the observed mean temperature was 35°F and represented a rise of 11°F above average temperature observed on the preceeding day. The thermal factor is (+7°F.) + (+11°F.) or (+18°F.). Rain was reported during six hours of the day. Substituting values from Table XI-14 in the formal yields: $I = 135\,(100 + 36 - 24)/100 = 151$ percent. Measured suspended particulate pollution was 280 micrograms per cubic meter on that day which, divided by the weather index, indicates that particulate pollution at the sampling station would be 185 micrograms per cubic meter under average meteorological conditions.

The foregoing example also may be used to illustrate use of the index in estimating the influence of wind direction on particulate pollution levels to the exclusion of the other three factors. If, for example, the prevailing wind was from the north in the example, the value 185 would be assigned to north winds rather than the measured 280. The 185 micrograms per cubic meter represents particulate pollution at the station under average meteorological conditions and can be compared with values similarly obtained for other wind directions. The computed values more truly represent the influence of upwind pollution sources on pollution levels than the measured values because the effects of wind speed, the thermal factor and the precipitation factor, which may be characteristically different for the various wind directions, have been taken into account.

BROAD-SCALE WEATHER PATTERNS AND POLLUTION LEVELS

Weather patterns existing over the Great Lakes region, the mid-North American Continent and even over larger areas have a marked influence on the pollution dispersing characteristics of the atmosphere in the Detroit-Windsor area. A knowledge of these influences makes possible a better understanding of various dispersion patterns. Synoptic conditions existing in the Detroit-Windsor area during the period August 7 to September 18, 1952 were tabulated in two groups according to suspended particulate pollution loadings at a network of air sampling stations. Mean synoptic conditions were plotted for the 10 most polluted days and nine least polluted days during the period. The mean position of the nearest cold front was added to the two maps (Figures XI-26 and XI-27). The ten days of high pollution were associated with a light southerly flow of warm air behind a high pressure center; the days of low pollution came

Table XI-14. Weather Factors for Computing the Weather Index of Pollution

Wind Speed Factor (F_v)		Thermal Factor (F_t)		Precipitation Factor (F_r)	
mph	Percent	Degrees F	Percent	Hours Duration	Percent
0	260	-38	-29	1	- 4
1	220	-34	-28	2	- 8
2	190	-30	-27	3	-12
3	170	-26	-26	4	-16
4	150	-22	-24	5	-20
5	135	-18	-23	6	-24
6	125	-14	-21	7	-27
7	120	-10	-18	8	-30
8	110	- 6	-12	9	-32
9	105	- 2	- 4	10	-33
10	105	+ 2	+ 4	11	-34
11	100	+ 6	+12	12	-35
12	95	+10	+20	13	-36
13	90	+14	+28	14	-37
14	85	+18	+36	15	-38
15	80	+22	+44	16	-39
16	80	+26	+52	17	-40
17	75	+30	+60	18	-41
18	75	+34	+68	19	-42
19	75	+38	+76	20	-43
20	75	...	...	21	-44
21	75	...	...	22	-45
22	75	...	...	23	-46
23	75	...	...	24	-47
24	70	...	...	..	...
25	70	...	...	..	...

with a northwesterly current of cool air.

Fredrick(20) identified 79 days (some consecutive) during the period July 1953 to September 1955 on which peak concentrations of suspended particulate and sulfur dioxide pollution occurred at most of the sampling stations in the Detroit-Windsor area, and 60 days when there was low pollution loading. The days were selected by inspection of graphs of pollution levels at a number of sampling stations. The synoptic situation for each day when high pollution existed was examined. The findings were:

a. 43 cases somewhat similar to Figure XI-26 occurred, with a south to southeast gradient and a high pressure area located to the northeast, east, or southeast of Detroit;

b. 11 cases of a southeast to south gradient, with a quasi-stationary ridge of high pressure northeast-southwest through the Great Lakes but with no definite center;

c. 9 cases with a light variable gradient, with no definite isobaric configuration;

d. 2 cases of a west to southwest current of warm air occurred with a ridge of high pressure extending from Bermuda westward to Tennessee with pressure gradient very light;

e. 1 case when a north-south ridge of high pressure moved east across the Great Lakes, the gradient at Detroit shifted from northwesterly to southerly;

f. 7 cases with a north to northwest gradient of cold, dry air, with a ridge or center of high pressure to the west of Detroit;

g. 4 cases where an area of low pressure moved by to the south or southeast, with the gradient at Detroit generally northeast to north;

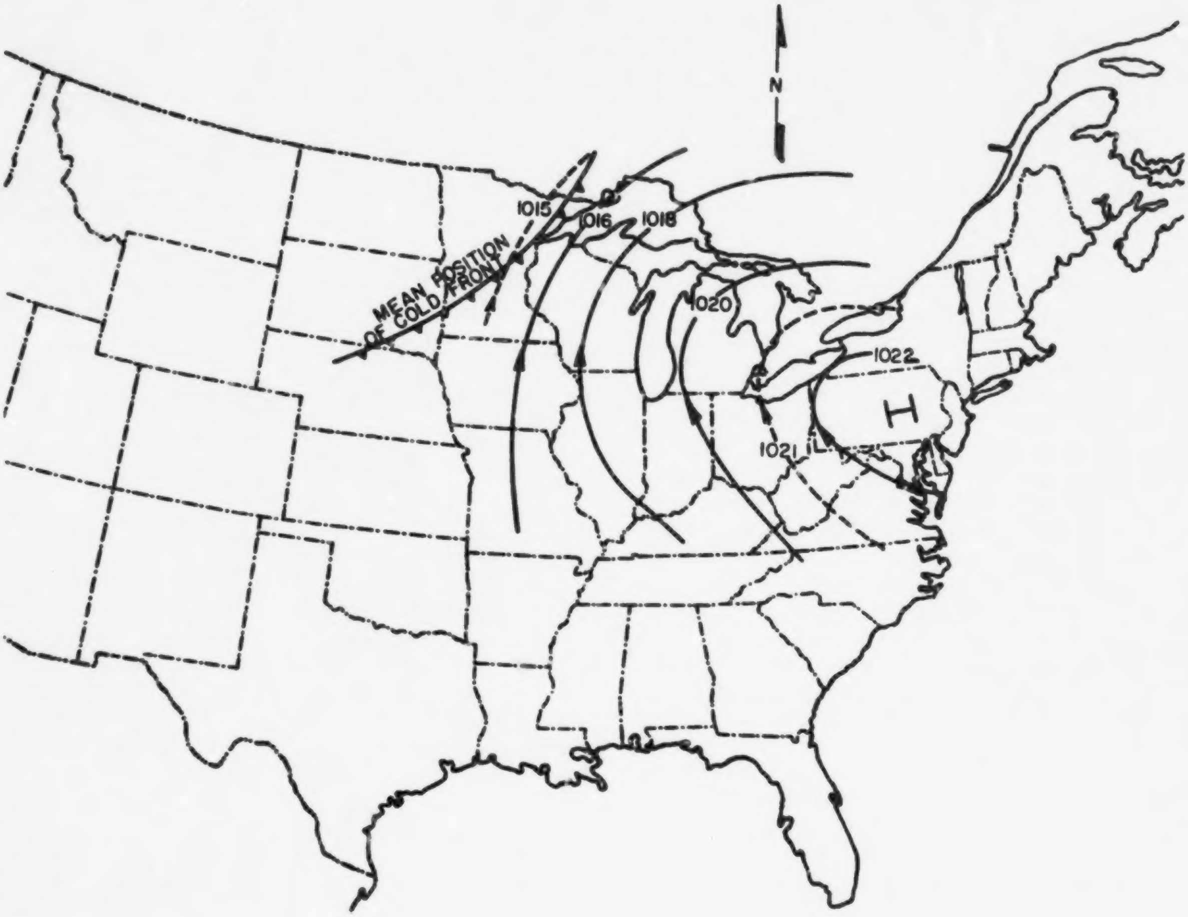


Figure XI-26. Average Atmospheric Pressure System for Ten Days of High Pollution August 7 Through September 19, 1952

h. 2 occasions when a cold front or occlusion passed Detroit during the day, with the gradient shifting from southeast to southwest.

Findings concerning the synoptic situation for days when low pollution existed were:

a. 24 cases were very similar to Figure XI-27, with a north to northwest gradient of cold, dry air and a definite center of high pressure in Manitoba or the American Midwest;

b. 16 cases involved a north to northwest gradient of cold, dry air, with a ridge of high pressure extending north-south across the Canadian and American Prairies but no definite center;

c. 7 cases indicated a cold frontal passage during the day and a south to southwest gradient at Detroit changed to west to northwest;

d. 8 cases when a low pressure area moved by to the south and a high pressure area was usually situated in Northern Ontario or Hudson Bay, the gradient at Detroit either remaining north to northeast or shifting from southeast to northwest;

e. 3 cases of a light, variable gradient and no definite isobaric configuration;

f. 2 instances in which a strong south to southwest current of warm air existed.

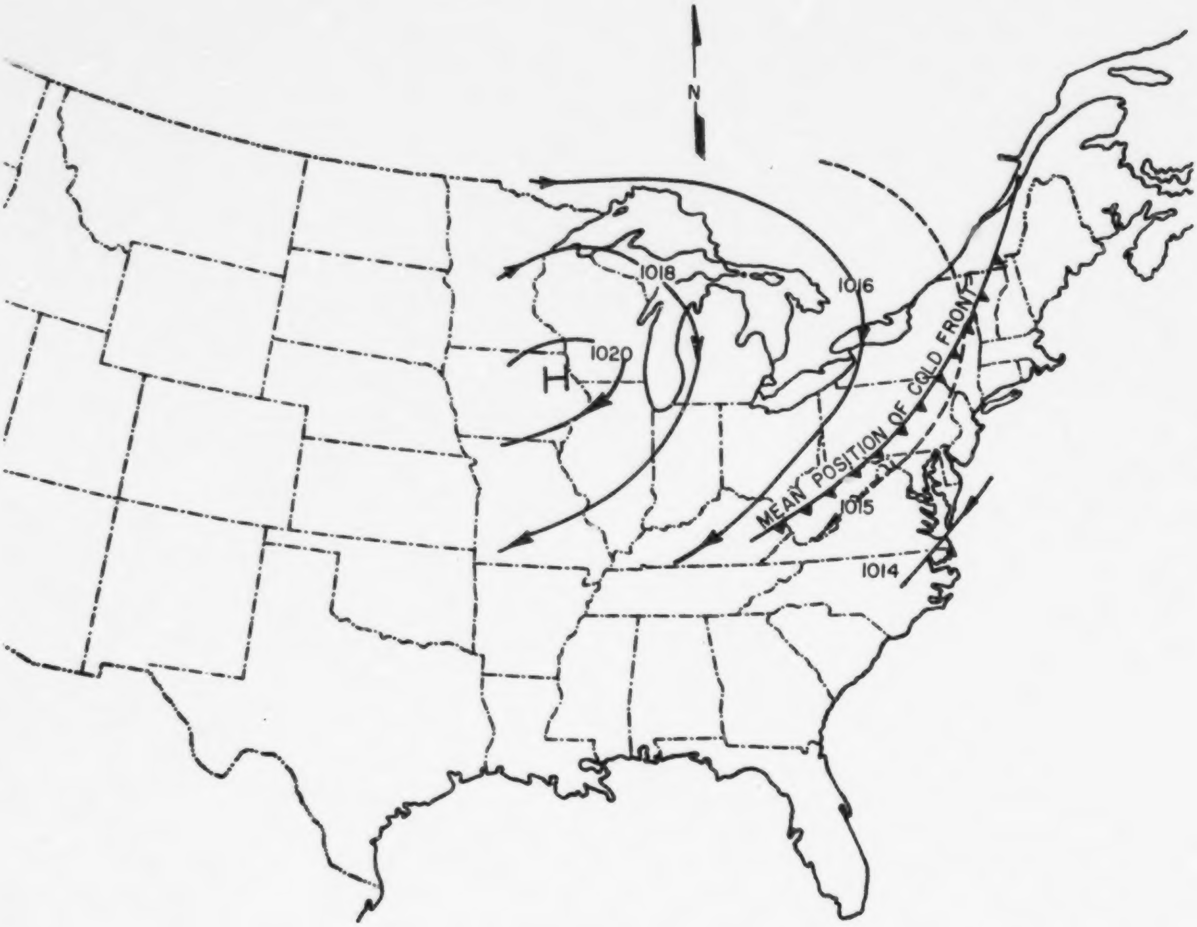


Figure XI-27. Average Atmospheric Pressure System for Nine Days of Low Pollution August 7 Through September 19, 1952

Of the 79 days selected as having unusually high pollution, the first four groups (65 cases), are in general agreement with Figure XI-26. Of the 60 days selected as having unusually low pollution, the first two groupings (40 cases) are in general agreement with Figure XI-27. Both findings of agreement with the synoptic maps were made on the premise that a ridge is a definite center of high pressure.

A subjective examination of synoptic charts for the 26-month period revealed 91 cases when peak pollution levels were to be expected but which were not selected as days of peak pollution from the measured pollution level curves. Similarly, 139 other synoptic situations conducive to low pollution levels were indicated by the synoptic charts but not by the pollution level curves. Pollution levels, therefore, are not always influenced to the same degree by synoptic conditions. The synoptic charts defined a time of peak pollution in about 72 percent of the cases and a time of low pollution about 46 percent of the time (Table XI-15). Further refinements are necessary to make the synoptic pattern an accurate indicator of pollution levels.

VISIBILITY MEASUREMENTS

Man's ability to see objects at a distance, or visibility, is obstructed by the presence of very small liquid or solid aerosols in the air. The

Table XI-15. Reliability of Use of Synoptic Weather Patterns as an Indication of Pollution Levels.

(July, 1953 to September, 1955)

	High pollution	Low pollution
Cases found by measurement of pollution	79	60
Other cases indicated by synoptic weather patterns	91	136
Weighted number of other cases indicated by synoptic weather patterns[a]	31	69
Percent of cases indicated by synoptic patterns verified by pollution measurements	72	46

[a] Pollution measurements from which the times of high or low pollution were selected tended to smooth out peaks and troughs of pollution levels for week-ends because the samples often represented 2- or 3-day averages. Therefore, the number of "other cases" was reduced in accordance with the number which occurred on week-ends in relationship to the proportion of cases found by pollution measurement on week-ends and on other days.

aerosols scatter part of the light going from the object to the eye. Some of the aerosols are the result of pollutants discharged from man's activities while others are the result of natural processes. Good visibility is desirable and therefore, the degree to which it is reduced by pollutants is a matter of concern.

Visibility measurements were made in downtown Detroit during parts of 1952 and 1953 using a transmissometer(14). The instrument consists of a 350,000 candlepower light source, a phototube receiver, an amplifier and a recorder. The light source was on the roof of the Federal Building and the receiver was about 800 feet away on the tenth floor of the Majestic Building, about 125 feet above ground. Results are in terms of percent light transmitted. These percentages may be converted to visual range for both day and night conditions by use of a conversion chart. In this discussion, only percentage light transmission is used. Aside from discarding results during times of precipitation, there are no means for compensating for reduction in light transmission caused by precipitation or fog.

Light transmission was best during the summer (July) and poorest in the winter (January) (Figure XI-28). Diurnal variation is greatest in the springtime (March - April) and least in summer and winter.

An automatic strip filter paper sampler was operated alongside the receiver of the transmissometer in the Majestic Building. The instrument draws air through a circle of filter paper 0.5 inch in diameter at a rate of 10 liters of air per minute for 25 minutes. It then quits sampling, moves the filter paper strip to a clean place and after 35 minutes of nonsampling status, the cycle starts over. Particulate matter in the air is removed by the filter. The extent of aerosol deposition was determined by measuring the percent of light (dominant wave length 400 mu) reflected from a sample spot as compared to that reflected from clean paper, which was considered 100 percent reflectance. Data obtained from use of this instrument were not closely related to light transmission values (Figure XI-29). The correlation coefficient between the two measurements was 0.365 indicating a lack of close correlation. Evidently the aerosols responsible for reduction in light transmission in the air and those which reduce light reflection from filter paper when deposited thereon are considerably different.

Light transmission data were considered in relation to wind direction, total weight of suspended particulate matter, daily temperature anomaly, the effect of precipitation on atmospheric clarity and light transmission through filter paper used to collect aerosols. Close relationships to these parameters were not revealed.

SOLAR ILLUMINATION

One effect of air pollution is to attenuate direct incoming solar radiation by reflection, scattering, and absorption. If this reduction is less in the country than in the city, illumination in the city expressed as a percentage of the country illumination, should be an indicator of pollution by aerosols.

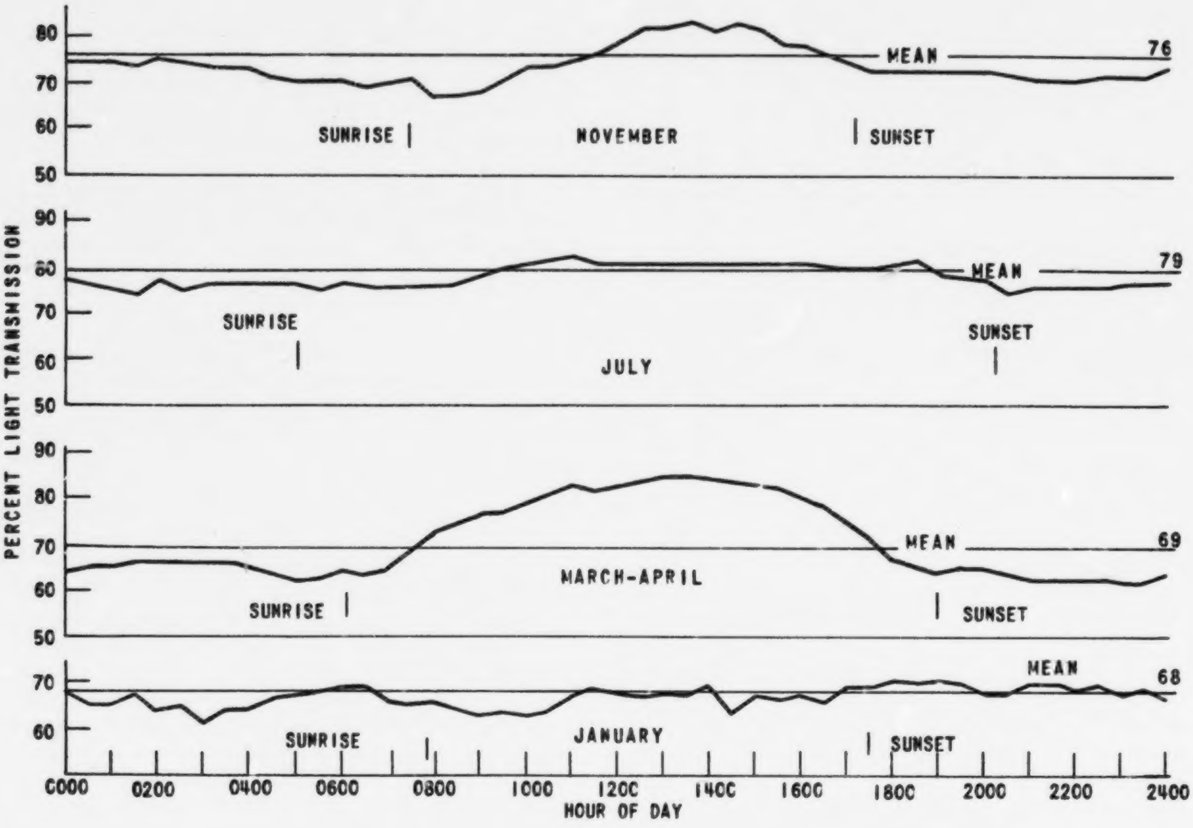


Figure XI-28. Mean Half-Hourly Light Transmission for Four Periods

Two standard Leeds and Northrup illuminometers(19, 99) were used to measure the total illumination from sun and sky. One was installed at the Windsor Airport in May, 1953 and moved to Harrow in November, 1953. A second illuminometer was installed on the top of the Windsor Tunnel ventilation building on London Street in Windsor in September, 1953, and in August, 1956, it was moved to the roof of the Bradings Brewery Building on Pitt Street in Windsor. The approximate elevation of the instruments above ground was 15 feet at the Windsor Airport and in Harrow, 125 feet on the tunnel building, and 60 feet on the Bradings Brewery Building. It was very difficult to obtain correct calibration of the two instruments. Illuminometers of this type must have frequent calibrations with a specially constructed calibration unit. The instruments are equipped with filters such that the light sensitive cells give a response comparable to that of the human eye. During the year 1954, cells in the instruments at Windsor and Harrow were interchanged at the middle of each month. Monthly comparisons could thus be made, although it was still impossible to make daily comparisons.

The trend in reduction of Windsor monthly average illumination (Table XI-16) suggests a relationship with the heating season. Hourly variation of illumination differences at the two stations do not indicate a pronounced pattern. However, this one-year sample is probably too short to portray the long-term trend, particularly since the months of September through November of 1954 had unusually good conditions for dispersion of pollution.

On October 16, 1956, an accurate calibration of the two illuminometers was made. Immediately following that calibration, a two-week sample of data was chosen for study. All days

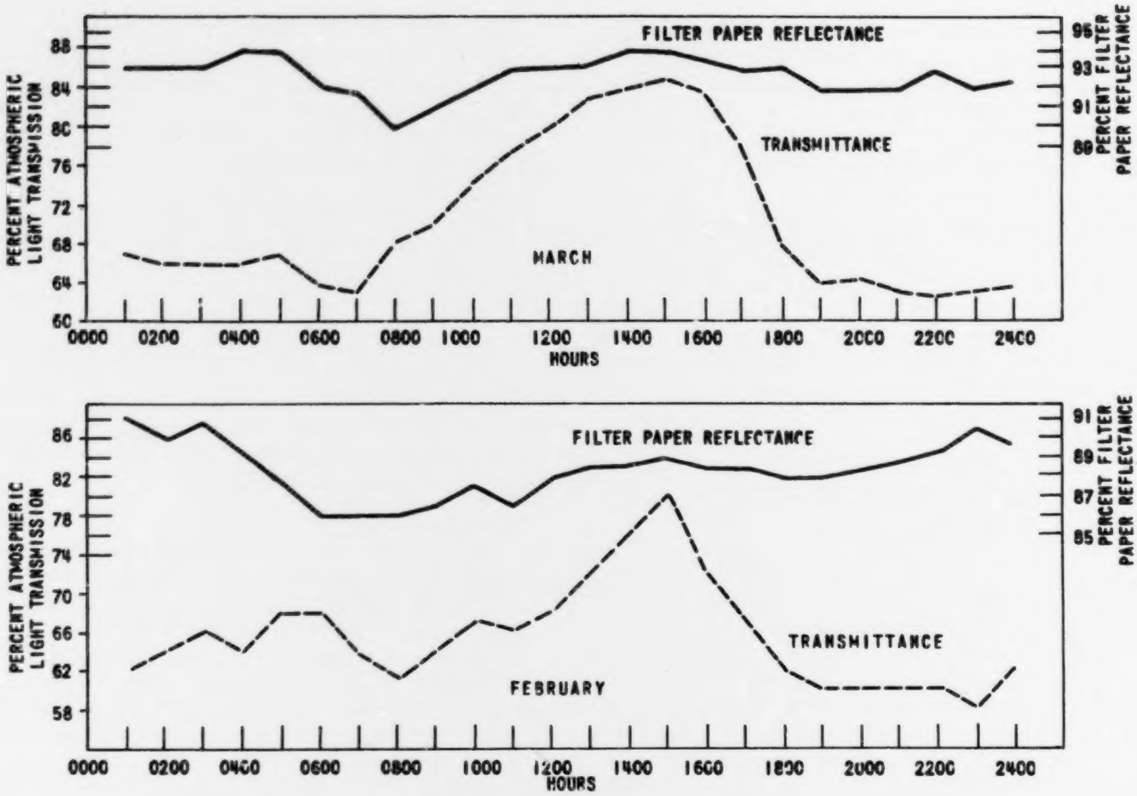


Figure XI-29. Transmissometer Measurements of Visibility and Reflectance of Aerosol Filters

Table XI-16. Daylight Illumination at Windsor and Harrow

Monthly mean illumination at Windsor as percent of that at Harrow, 1954		Hourly mean illumination at Windsor as percent of that at Harrow, 1954		Hourly mean illumination at Windsor as percent of that at Harrow, Oct. 17, 21, 28, 1956	
Month	Percent	Hour	Percent	Hour	Percent
Jan.	82	0600	100	0800	65
Feb.	86	0700	97	0900	75
Mar.	95	0800	91	1000	80
Apr.	90	0900	92	1100	87
May	90	1000	93	1200	92
June	94	1100	96	1300	92
July	95	1200	96	1400	86
Aug.	94	1300	94	1500	79
Sept.	96	1400	92	1600	73
Oct.		1500	91	1700	83
Nov.	94	1600	88	1800	88
Dec.	80	1700	89		
		1800	91	3 Days	84
Year	92	1900	98		
		2000	92		

with any cloudiness were eliminated from the sample. October 17, 21, and 28 were the only remaining days for which data could be analyzed. The diurnal trend is similar to that found in the 1954 analysis but the percentage reductions are larger (Table XI-16).

INTERAREA TRANSPORT OF POLLUTION

Pollution levels in a locality may be considered the sum of that produced locally and that carried into the area from other regions. Pollution arising in Detroit-Windsor will effect areas some miles away and pollution arising in rural and small urban areas will effect Detroit-Windsor. Pollution existing in rural and small urban areas and transported into the Detroit-Windsor area is largely of natural origin, under most circumstances.

Pollution measurements made using high volume air filters at one station in Harrow and at four to six stations in Detroit-Windsor were used to evaluate interarea transport of suspended particulate pollution. It was concluded from these data, when considered with wind direction data, that suspended particulate pollution arising in Detroit-Windsor may reach Harrow in concentrations of about 34 percent of what they were when in the Detroit-Windsor area. It was estimated that 36 percent of the average suspended particulate pollution in the Detroit-Windsor area was carried in from outside and that the remainder originated within the area. Several assumptions and sources of bias existed in the analysis, but it was felt that the results were of the right order of magnitude.

NATURAL ATMOSPHERIC RADIOACTIVITY AS AN INDEX OF STABILITY

It is known that the rocks and soil at the earth's surface are continually emitting the gaseous radioactive emanations radon, thoron, and actinium. After their emission, the vertical distribution of these emanations is determined by atmospheric mixing and diffusion. Generally their concentrations in the air just above ground level are low during periods of vigorous mixing. Vigorous mixing depends on large lapse rates and high winds. Hence, if close correlation could be established between the intensity of natural radioactivity and lapse rate and wind speed acting jointly, a convenient dispersion index would be provided.

In 1952, the Industrial Hygiene Division of the Detroit Department of Health started measuring natural atmospheric radioactivity(66), hereinafter abbreviated nra. The Division's data were analyzed by the Technical Advisory Board. A quartz fiber electrometer was used to measure radioactivity of material collected on filter papers. Air was drawn through a one-inch disc of filter paper at a rate of 0.5 cubic feet per minute for 30 minutes. The disc was placed in the chamber of the electrometer. An initial reading was taken within five minutes and a final reading 30 minutes later. Background drift was subtracted, the result doubled, and the data reported as the number of scale divisions per hour rather than absolute radiation units. Measurements were made daily at 0800 and 1500 EST at Herman Kiefer Hospital.

The influence of weather on observed radon concentrations in surface air falls into two classes; those which affect the rate of emission of the emanations and those which affect their rate of diffusion. Unless the first type of influence is small in comparison to the second, nra is unlikely to provide a good stability or diffusion index. Precipitation reduce the exhalation and solar radiation, and an increase in temperature increases it; falling atmospheric pressure causes an increase in exhalation, rising pressure a decrease. Frost decreases exhalation sharply and may stop it. Wind may suck the emanations from the ground capillaries with the result that increasing winds give increasing emanations(33). Increasing wind speed which increases emanation also improves diffusion. Atmospheric temperature inversions suppress vertical motion of air and inhibit dispersion. Raindrops have a tendency to carry radioactive particles from the upper air into the lower air and to the ground, particularly during thundershowers. The radon content of surface air represents the resultant effect of all these influences. Where one element has a twofold effect, such as wind speed and rainfall, the net effect may be too small to detect. The influence of elements which influence only emanation rate or only dispersion should be more readily evaluated.

Four-week averages of nra were computed from three years' data, using only 0800 EST values. The broad trend of high values in the fall and low values in spring are evident and variations in averages for the four-week periods are large (Table XI-17).

Table XI-17. Seasonal Variation in Natural Atmospheric Radioactivity in Detroit, 1952 to 1955 - (Readings at 0800 EST)

	Jan.												Dec.
Number of four-week period	1	2	3	4	5	6	7	8	9	10	11	12	13
Natural radioactivity (arbitrary units).	43	33	30	31	38	51	68	82	91	94	93	84	63

Simple correlations were computed between nra and suspended particulate pollution levels measured by a high volume filter at a point one and one-half miles northeast of Herman Kiefer Hospital. From data collected during the period July 1953 through December 1954, separations were made by seasons (Dec., Jan., Feb. taken as winter, etc.) and correlation coefficients were computed between the 0800 and 1500 EST nra values and their means and suspended particulate pollution (Table XI-18). The 0800 EST nra values are more directly related to pollution levels than the 1500 EST nra values, and in only the fall season was the average nra value more closely related to pollution than the 0800 or 1500 EST values.

Simple correlations were undertaken using 0800 EST observations to determine the effect of rain or damp ground on the relationship between particulate pollution and nra. The criterion for damp days was taken to be "rain observed at Detroit City Airport during the hour ending 0800 EST, or not at 0800 EST but during the hours ending at 0700 and 0900 EST, or a total of 0.10 inches between midnight and 0600 EST." There were 18 days between May and November of 1953 and 1954 which met the criterion on which nra and suspended particulate pollution were also measured. For comparison, a sample of 18 dry-ground days was chosen by matching each of the damp days with the nearest dry day for which the other measurements were available. Nra and suspended particulate pollution were correlated for each of the two groups. The values for dry and damp ground were 0.843 and 0.207 respectively, compared to 0.590 which is significant at the one percent level. It was concluded that rain destroyed the correlation. Nra readings were also correlated with light reflectance readings made on the same filters used to measure nra. The method of selecting damp and dry days and the time period was the same as with suspended particulate correlations but the sample increased to 27 days since no days were lost due to a lack of suspended particulate pollution measurements. The correlation coefficients were 0.326 for damp and 0.413 for dry days as compared to 0.381, the value significant at the five percent level. Therefore, on the basis of these two results, rainy days were excluded from further analyses of weather influences on nra.

A multiple regression type statistical analysis was done using 0800 EST values of nra obtained in June, July and August 1954. These were values indicated as most likely to be directly related to weather influences and pollution levels. Values taken on days when rain had been reported at Detroit City Airport after 1800 EST the previous day were excluded. The total sample consisted of 38 days. The quantities considered in the analysis were:

Table XI-18. Correlation of Natural Atmospheric Radioactivity and Suspended Particulate Pollution - July 1953 to December 1954

Season and number of observations	Correlation Coefficients				
	Observed values			Significant Values	
	0800 EST	1500 EST	Mean	5 Percent	1 Percent
Spring (32 days)	0.113	0.091	0.127	0.347	. . . . .
Summer (35 days)	0.593	0.023	0.528	0.335	0.430
Fall (35 days)	0.413	0.425	0.460	0.335	0.430
Winter (40 days)	0.451	0.029	0.284	0.312	0.403

X_1 Measured natural radioactivity

X_2 Thermal factor in degrees F. (The algebraic sum of the 24 hour temperature change and deviation of daily temperature from normal temperature for the day).

X_3 Wind speed in mph. at 0730 EST

X_4 Barometric pressure in hundredths of an inch of mercury over 29.00 inches at 0730 EST

X_5 Temperature minus dewpoint temperature at 0730 EST (an indication of relative humidity)

(all meteorological observations from Detroit City Airport)

A series of numerical multiple regressions were computed between nra and various combinations of weather factors. The thermal factor was always included since it was significantly correlated with nra. (0.652 correlation coefficient with 0.413 significant at the one percent level.) Multiple correlation coefficients were computed for each regression equation and the standard error of estimate was computed for comparison with the standard deviation of observed nra (Table XI-19). The several partial regression coefficients in the table numerically express the relationships, showing that as nra increases, the thermal factor increases; nra decreases as pressure increases; nra decreases as wind speed increases; and nra increases as relative humidity decreases. Despite the fact that the data used were selected as being most likely to reveal correlation, the best standard error of estimate that was achieved was 33 as compared to the standard deviation of measured nra of 47. If rainy days and data from all seasons were used the problem would be more complex and the solution less accurate.

The present analysis and theory indicate that radon emissions are not constant, even for dry summer days, as evidenced by the dependence of nra on pressure and humidity. Therefore, variations in nra do not necessarily indicate a variation in the lapse rate or in overall turbulence and diffusion. The thermal factor is shown to be related to nra but this may be due partly to increased emissions resulting from rising temperatures.

It is concluded that measurements of natural atmospheric radioactivity levels cannot be considered to indicate stability or turbulence with sufficient accuracy to warrant their use for that purpose.

Table XI-19. Statistical Data From Correlation of Natural Atmospheric Radioactivity and Weather Factors.

Independent variables	Regression equation	Correlation Coefficients		Std. deviation of X_1	Std. error of estimate
		Observed	Significant at 1% level		
X_2	$X_1 = 68 + 3.3 X_2$	0.65	0.41	47	37
X_2, X_3	$X_1 = 113 + 3.3 X_2 - 1.3 X_3$	0.68	0.48	47	36
X_2, X_4	$X_1 = 84 + 3.6 X_2 - 2.2 X_4$	0.67	0.48	47	37
X_2, X_3, X_4	$X_1 = 143 + 3.7 X_2 - 1.4 X_3 - 3.7 X_4$ . . .	0.73	0.53	47	34
X_2, X_3, X_4, X_5	$X_1 = 122 + 2.7 X_2 - 1.3 X_3 - 3.5 X_4 + 1.6 X_5$	0.75	0.57	47	33

X_1 = natural radioactivity and considered dependent on other variables;
X_2 = thermal factor; X_3 = barometric pressure; X_4 = wind speed;
X_5 = difference between temperature and dew point.

Chaptur XII

VESSEL SMOKE AND ITS CONTROL

INTRODUCTION

The major factor leading to the formulation by the United States and Canada of the joint Air Pollution Reference of January 1949, was the excessive emission of smoke and air pollutants by shipping on the Detroit River. For a number of years the cities of Detroit and Windsor had carried on programs of smoke and air pollution control with respect to land-based sources of pollution which were within their jurisdiction, but municipal, state or provincial authorities were not able to effectively regulate smoke from vessels plying the Detroit River. In the circumstances, the municipal authorities were severely handicapped in their efforts to reduce the over-all pollution levels; the large volume of shipping traversing a relatively narrow waterway had in a sense, the effect of a source of pollution highly concentrated in time and place. The residential and mid-town districts on either side of the river were subjected by the river shipping to such volumes of dense smoke as could be termed a public nuisance of serious dimensions.

The objectives of the Technical Advisory Board study of vessel smoke emission were closely related to the questions posed in the Terms of Reference. These objectives were as follows:

1. To establish, by observations of the density or shade of smoke emitted from vessels plying the Detroit River, the extent to which such pollution violated reasonable standards.

2. To consider what preventive or remedial measures would be most practical for the abatement of excessive smoke and air pollution.

VESSEL TYPES, NUMBERS, AND TRAFFIC

The type of vessel found most suitable for navigation in the Upper Lakes and Lake Erie and for accommodating the maximum volume of cargo is long, narrow, of 10,000 tons capacity or more, and is unsuited to transocean service. The "canaler" type required to navigate the Welland Canal and the canals of the St. Lawrence is much smaller, of 2,000 to 3,000 tons capacity, and is used to transship freight from the bulk carriers to ocean-going vessels. It is anticipated that the opening of the St. Lawrence Seaway in 1959 will result in the ready access of the Lower St. Lawrence to Great Lakes bulk carriers, increased use of the Upper Lakes by ocean-going traffic, and modification of Upper Lakes shipping to suit it to ocean service.

The Great Lakes fleet consists of about 750 vessels with a total gross tonnage of about 3,500,000 tons. The carrying capacity of the fleet reached the 5,000,000 gross ton mark in 1954 for the first time in history, and since has fluctuated slightly below this figure. About three-quarters of the total tonnage of carge is carried by United States vessels.

A summary of the Great Lakes fleet itemized by vessel type, number and total gross tonnage is given in Table XII-1. A similar itemization with respect to cargo carrying capacity is shown in Table XII-2. These tabulations have been abstracted from the Annual Report, Lake Carriers' Association, 1955.

The various types of firing equipment on Great Lakes vessels operation on the Detroit River are listed in Table XII-3. It is apparent that the Canadian Fleet contains a considerably larger percentage of oil-fired and diesel equipped vessels in comparison with the U. S. Fleet. However, in the vessel types using coal for fuel, the United States Fleet contains about a five-fold greater percentage of vessels equipped with automatic firing as compared with the Canadian Fleet. Since the winter lay-up season of 1951-52, forty-three hand-fired vessels of both fleets have been equipped with underfeed stokers. This process of conversion, after a

Table XII-1. Summary of the Great Lakes Fleet by Types and Trades, Number and Total Gross Tonnage, and United States and Canadian Registry for 1955.

(Only vessels of 1000 or more gross registered tons are included.)

Type and Trade	U. S. Registry		Canadian Registry	
	Number	Total Gross Tonnage	Number	Total Gross Tonnage
Bulk Freighters in the Iron Ore trade	260	1,874,746	54	403,472
Bulk Freight, Self Unloading Vessels	51	307,045	11	31,820
Bulk Freight Vessels in Mixed Trades	41	123,312	139	295,248
Bulk Freight Barges in Mixed Trades	7	20,964	11	31,745
Package Freighters	--	---	21	53,181
Oil Tankers	59	112,754	40	96,770
Car Ferries	31	90,545	1	1,052
Passenger Steamers	7	28,721	5	13,080
Total	456	2,558,087	282	926,368

Total Number of Vessels 738

Total Gross Tonnage 3,484,455

Table XII-2. Summary of Carrying Capacity of Great Lakes Fleet by Nationality Types and Trades For the Season 1955

Type and Trade	U. S. Registry		Canadian Registry	
	Number	Carrying Capacity Gross Tons	Number	Carrying Capacity Gross Tons
Bulk Freighter in the Iron Ore Trades	260	2,809,550	54	579,000
Bulk Freighter, Self Unloading Vessels	51	438,397	11	40,550
Bulk Freight Vessels in Mixed Trades	41	186,300	139	443,200
Bulk Freight Barges in Mixed Trades	7	34,600	11	56,000
Package Freighters	--	---	21	71,000
Oil Tankers	59	180,550	40	131,800
Total	418	3,649,379	276	1,321,550

Total Number of Vessels 694

Total Carrying Capacity 4,970,947 gross tons.

Table XII-3. Firing Equipment of Great Lakes Vessels

Canadian Companies	Number	Percent
Oil fired	66	33.1
Diesel	24	12.0
Underfeed Stoker - Coal. .	9	4.5
Other Stoker types - Coal.	3	1.5
Hand-Fired - Coal	81	40.7
Unknown	16	8.0
Total	199	99.8
United States Companies	**Number**	**Percent**
Oil fired	68	16.3
Diesel	35	8.4
Underfeed Stokers	23	5.5
Other Stoker - fired . . .	99	23.7
Hand-fired	142	34.1
Unknown	50	12.0
Total	417	100.0

relatively slow start, has been accelerated in the last two years.

Within recent years, especially on the Canadian side, the trend in new vessel construction has been to diesel or oil firing. In 1955, one oil-fired package freighter and four canal sized vessels were added to the Canadian Fleet. Two canal sized vessels were removed. Seven new Canadian vessels have been built and commissioned for service in 1956. These are all equipped with diesel engines.

In 1955, five vessels of the United States Fleet were scrapped and nine other vessels were withdrawn from service and used as floating grain storage warehouses. One new vessel, a large coal burning self unloader, was commissioned, but no commercial U. S. vessels were under construction as the year ended.

Many of the ships now plying the Great Lakes were built in the first decade of the century. The accompanying two graphs, (Figures XII-1 and XII-2) show the distribution of ages of vessels currently listed by the Lake Carriers' Association and the Dominion Marine Association. These data are self-explanatory and bear out the assertion that "vessel hulls never die." Of the total number of Canadian vessels, 37 percent are over 30 years old, and of the United States vessels about 50 percent are over 45 years of age.

Shipping of European registry is already playing a significantly increasing part in Great Lakes commerce. In 1954, 100 vessels made 267 trips; the following year 119 vessels made 329 trips. This traffic is expected to increase with the completion of the St. Lawrence Seaway.

OBSERVATIONS OF VESSEL SMOKE EMISSION

The reference standard used to estimate smoke emission density from a stack is the Ringelmann Chart. The chart consists of a numbered series of sheets of white paper criss-crossed by black lines of differing thickness. When the sheets are held at a distance of about 50 feet from the observer, on a level with the eye, the black and white merge into shades which can be matched with the smoke observed at the same time. Ringelmann numbers range from 0 to 5, corresponding to no smoke or clear conditions and increments of 20, 40, 60, 80 and 100 percent black smoke respectively. Further information on the use of Ringelmann Charts is available in U. S. Bureau of Mines Circular 6888. For field use, small cards showing numbered sectors in a circular pattern, and shades varying by 20 percent increments from white to black are considered acceptable.

The performance of a proportion of the vessels as they traverse the Detroit River is observed with binoculars from either side of the Detroit River by trained personnel who record the duration and density of smoke emission, the time of day and the total time of observation. Daily logs are prepared which, in addition to the above, note the name of the vessel, ownership, observation point, and compliance or noncompliance with smoke emission "objectives" defined later. When possible, at the time of occurrence, grossly excessive emissions are called to the attention of the masters of the vessels concerned, by shore-to-ship telephone.

Observations, by the method described, of the density and duration of smoke emission were commenced from the Canadian side of the river on July 8, 1949 and continued to November 11, 1949, by an observer carefully instructed by experienced inspectors of the Smoke Abatement Departments of Detroit and Windsor. Similar measurements by two trained Canadian

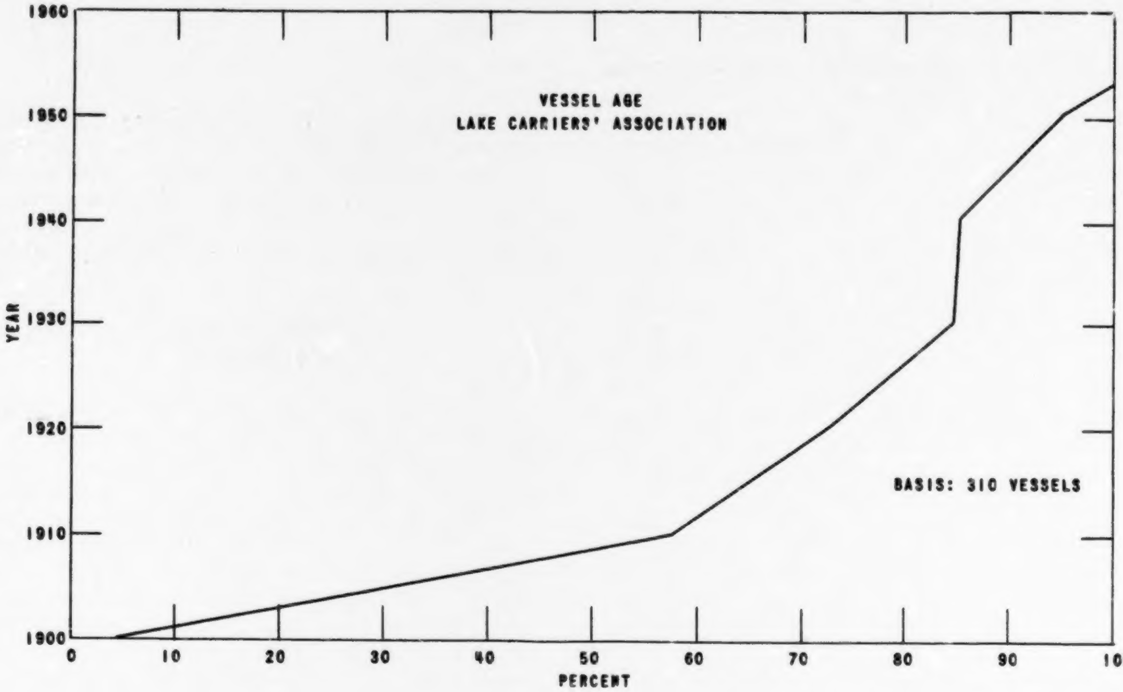


Figure XII-1. Percentage of Vessels Constructed Prior to Given Year

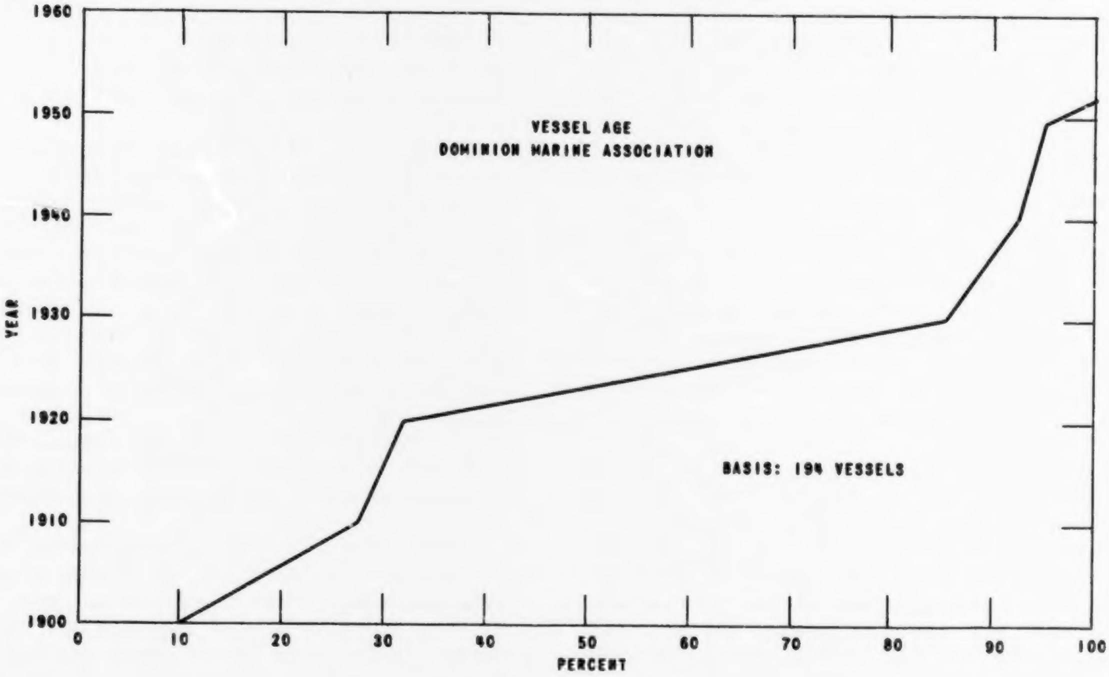


Figure XII-2. Percent of Vessels Constructed Prior to Given Year

observers were continued in succeeding years, with participation on a part-time basis by staff from the City of Detroit. Since 1955, Canadian observations have been supplemented by concurrent observations from the Detroit side of the river by an observer employed by the United States Section of the Technical Advisory Board. Field operations were usually commenced late in April or early in May and continued until about the middle of November to include almost the entire navigation season of each year.

The detailed data on the smoke performances of vessels plying the Detroit River have been presented to the International Joint Commission in a series of Annual Progress Reports which are listed in Appendix "A" of Chapter III. These reports have been distributed, with the approval of the Commission, to every vessel owner and operator on the Great Lakes, to the Lake Carriers' and Dominion Marine Associations, and to the appropriate control agencies of the municipalities along the Detroit River. Limitations of space permit the presentation of only a condensed summary of the very large body of information accumulated over the years of the study.

A comparison of vessel smoke emission for the navigation seasons of 1949 through 1957 is presented in Tables XII-4, XII-5, and XII-6.

As shown in Table XII-4, the total number of vessels under observation in each navigation season has varied from a low of 442 in 1949 to a high of 659 in 1955. The data are indicative of the proportion of vessels that could meet, in all passages of the river, those emission standards that specify a top limit of No. 2 Ringelmann smoke. For example, in 1950, about 88 percent of the vessels observed plying the river emitted smoke of No. 3 Ringelmann or darker shades during one or more passages, whereas 7.5 percent of them consistently emitted either no smoke at all or only light permissible smoke of No. 1 Ringelmann in all passages of the river.

Vessel performance with reference to total number of passages is shown in Table XII-5. To clarify the difference between Tables XII-4 and XII-5, a few more than half the vessels traversing the river in 1956 emitted No. 3 Ringelmann smoke or darker either occasionally or habitually, as shown in Table XII-4, whereas, as shown in Table XII-5, the total number of passages during which No. 3 Ringelmann smoke was emitted had dropped to a little more than a third of the total. The difference in the two tables means that many ships, which in earlier years were operated unsatisfactorily, had their smoke performance improved through effective control efforts.

Table XII-4. Smoke Performance Record For Vessels Passing Through the Detroit River

Number of Vessels Emitting Smoke at Indicated Density During Navigation Seasons

Year	Ringelmann Number			
	0-No.1	No.2	No. 3 or darker	Total Vessels
1949	51	21	370	442
1950	35	20	411	466
1951	115	26	475	616
1952	132	47	462	641
1953	126	27	439	592
1954	224	54	237	515
1955	230	78	351	659
1956	206	75	310	591
1957	261	64	297	622
		Percentage		
1949	11.5	4.8	83.7	
1950	7.5	4.3	88.2	
1951	18.7	4.2	77.1	
1952	20.6	7.3	72.0	
1953	21.3	4.5	74.1	
1954	43.5	10.5	46.0	
1955	34.9	11.8	53.3	
1956	34.8	12.7	52.5	
1957	41.9	10.3	47.8	

The nature of the improvement explained by the comparison of Tables XII-4 and XII-5 is more strikingly shown in Table XII-6, in which total minutes for which vessel passages were observed are recorded.

The striking improvement in vessel performance over the years 1950 through 1957 is shown graphically in Figures XII-3 and XII-4. The consistently rising slopes of all four curves in Figure XII-3 to the end of 1954 show the rate at which improvement was effected; the levelling off shown in 1955, 1956 and 1957 is highly

Table XII-5. Vessel Smoke Performances

Number of Passages

Year	Ringelmann Number 0 - No. 1	No. 2	No. 3 or darker	Total Passages
1949	151	---	1010*	1161
1950	127	69	1192	1388
1951	893	584	2608	4085
1952	831	525	2207	3563
1953	1012	347	11718	3077
1954	1360	316	800	2476
1955	2354	690	1503	4547
1956	1372	593	1057	3022
1957	2398	525	1144	4067
		Percentage		
1949	13.0	---	87.0*	
1950	9.1	5.0	85.9	
1951	21.9	14.3	63.8	
1952	23.35	14.75	61.9	
1953	32.9	11.25	55.85	
1954	54.93	12.76	32.31	
1955	51.77	15.17	33.06	
1956	45.40	19.62	34.98	
1957	58.96	12.91	28.13	

* This total for 1949 includes passages during which No. 2 Ringlemann smoke was also observed.

Table XII-6. Vessel Smoke Performances

Total Minutes Observed

Year	Ringelmann Number 0 - No. 1	No. 2	No. 3 or darker	Total Minutes
1949	6130	8969	17410	32509
1950	12331	4314	17031	33676
1951	31447	12136	23336	66919
1952	31001	12268	19759	63028
1953	31276	6632	14380	52288
1954	34074	4678	5190	43942
1955	66035	11401	9984	87420
1956	36999	9291	7145	53435
1957	53671	7397	7378	68446
		Percentage		
1949	18.8	27.6	53.6	
1950	36.5	12.8	50.7	
1951	47.1	18.15	34.75	
1952	49.4	19.45	31.15	
1953	59.8	12.7	27.5	
1954	77.55	10.65	11.8	
1955	75.54	13.04	11.42	
1956	69.23	17.39	13.38	
1957	78.41	10.81	10.78	

singificant, and indicates that a change in the nature of further efforts is necessary. The rate at which poor performance decreased until the end of 1954 is shown in Figure XII-4.

Early in this study it became apparent that diesel equipped and oil-fired vessels showed the best smoke performance, and that with the exercise of reasonable care in the operation of the combustion equipment, their smoke emission could be controlled within the limits prescribed by the regulations of the cities of Windsor and Detroit. Coal burning vessels equipped with spreader stokers or underfeed stokers also demonstrated their capability of being operated within reasonable smoke emission limitations, although the performance was not as consistent as with vessels in the previous class. Hand-fired coal burning vessels with Scotch marine boilers performed erratically and showed the heaviest smoke emission. In fact, the hand-fired vessels, of which there is a relatively large number in the Great Lakes fleet, constituted the core of the vessel smoke problem. After several years of study, it became apparent that further satisfactory progress in the solution of the problem could only be achieved by the large scale conversion of the combustion equipment on such hand-fired vessels to automatic firing methods.

SMOKE EMISSION OBJECTIVES

At its executive sessions in Washington, D.C., December 11-13, 1951, the Board considered further procedures to be followed in controlling excessive smoke emission from vessels plying the Detroit River. A plan which commended itself to the Commission involved the establishment of definite smoke emission

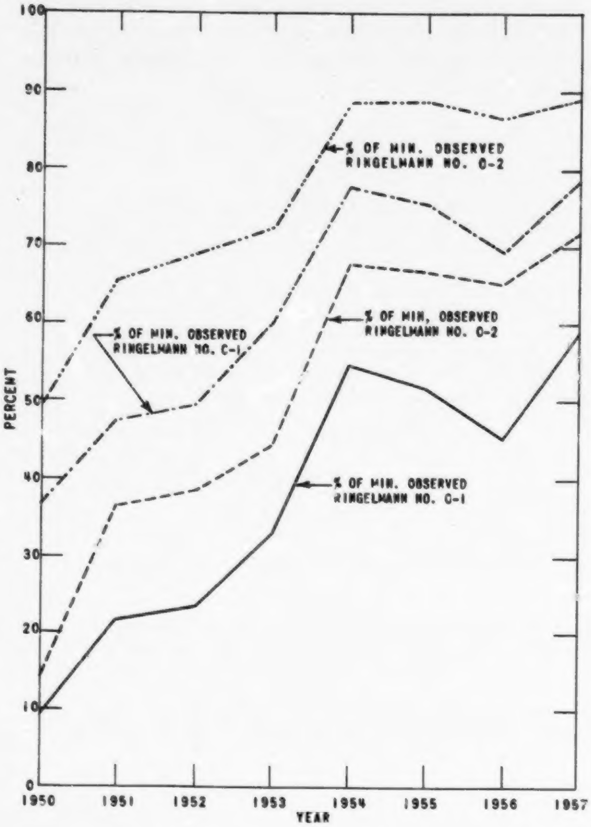


Figure XII-3: Vessel Smoke Performances for the Years 1950 through 1957

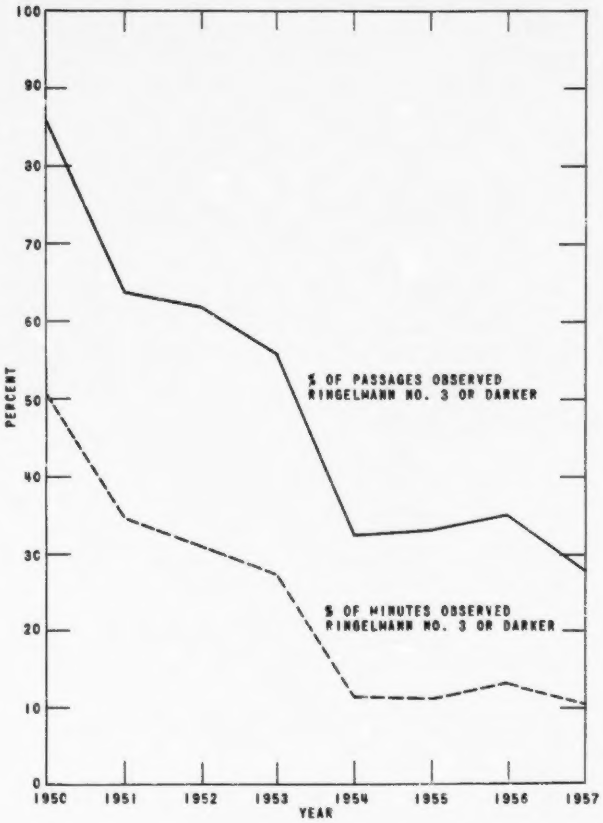


Figure XII-4: Vessel Smoke Performances for the Years 1950 through 1957

objectives which would be subject to revision as circumstances warranted. The Board would seek to achieve compliance with these "Objectives" by all shipping on the Detroit River and would report to the Commission and to vessel owners and operators the degree of compliance with the smoke limitations set forth in these "Objectives".

In February 1952, the following circular letter was issued by the International Joint Commission to all lake vessel owners and operators in the United States and Canada. This letter sets forth the "Objectives for Air Pollution Control" for the 1952 navigation season.

This program was heartily endorsed by the cities of Detroit and Windsor and other municipalities along the Detroit River.

A second public hearing on the vessel smoke problem was held by the Commission on June 5, 1953, at Detroit, Michigan. The Technical Advisory Board reported to the Commission the findings of the studies of smoke conditions on the Detroit River under the voluntary control program.

During the above hearing, representations were made to the Commission by the air pollution control officers of the municipalities that the voluntary control program be replaced, as soon as practicable, by a system of legal control based on legislation regulating air pollution in the cities of Windsor and Detroit. It was proposed that the necessary authority be established, by legislation if necessary, to administer control regulations and to impose penalties by appropriate courts for infractions of such regulations.

In 1953, and succeeding years, following the procedure established in 1952, circular letters were issued by the Commission before the opening of each navigation season to indicate the revisions of objectives recommended by the Board in the continuation of efforts to abate the smoke nuisance under the voluntary control program.

Re: Air Pollution Reference
12 January, 1949

"Under date of July 17, 1950, when requesting certain confidential information from you as to vessel equipment, the Commission explained the nature of the work it was undertaking in regard to air pollution in the Detroit River area. It is probable that this work will lead to an international agreement devised to abate and control air pollution in that area.

In addition to a study of the information submitted by you, observations of smoke emitted from vessels were made during the shipping seasons of 1949, 1950, and 1951. Although highly commendable work was done by the Engineering Advisory Committee of the Lake Carriers' Association and of the Dominion Marine Association in its Great Lakes Air Pollution Abatement Program, and although some improvement in the general average emission of smoke from vessels was noted for the year 1951, it is very evident that the personnel of many vessels are not cooperating satisfactorily in abating smoke. They are producing much more smoke than is necessary with the equipment now installed.

Methods of lessening smoke production include:

1. An educational program for ship personnel.
2. The use of correctly specified fuel.
3. The installation of smoke indicators of any type that will keep the firemen continuously informed as to smoke production.
4. The use of correctly designed jets for supplying over-fire air. (The aforementioned Engineering Advisory Committee has developed jets for stoker-fired water-tube boilers and is now working on jets for hand-fired Scotch marine boilers).

Realizing that it is impractical for all vessels to operate immediately within desirable smoke limits, the Commission has established the following reasonable set of objectives, for 1952 only, that takes into consideration the type of equipment installed in the vessel:

1. For stoker-equipped coal-fired water-tube boilers, the maximum emission shall be not more than No. 2 Ringelmann for 80 percent of the time, based on a time period of one-half hour, and not more than No. 3 for 20 percent of the time. This means that the production of No. 4 or No. 5 smoke, or more than 6 minutes in any half hour of smoke darker than No. 2, up to and including No. 3, would be declared unreasonable under all ordinary circumstances.
2. For other types of coal-fired equipment, the emission will be considered unreasonable if No. 4 Ringelmann or darker is emitted practically continuously.
3. Oil-fired vessels will be expected ordinarily to stay within the smoke limitations of the cities of Detroit and Windsor which permit smoke equal to but not darker than No. 2 up to 4 minutes in one-half hour.

While the above objectives for 1952 appear lenient they should not be used to defer installation of necessary equipment to abate smoke. As time makes possible the establishment of improved methods and proper equipment, the objectives will become more restrictive.

The Commission plans to continue the observation of vessel smoke emission during 1952. It plans to notify the owner of each vessel that is observed to emit an unreasonable amount of smoke while in the Detroit River area. It also plans to notify the owner of each vessel that is observed to make an outstanding record of minimum smoke production as related to its equipment.

Your cooperation in this important program is requested and would be greatly appreciated.

A letter in like terms is being sent by the Chairman of the United States Section of the International Joint Commission to all United States' vessel owners and operators making use of the Detroit River."

Yours faithfully,

(sgd.) A. G. L. McNaughton
Chairman, Canadian Section
International Joint Commission.

Smoke emission objectives for vessels, based on the type of firing equipment, have been recommended to the Commission each year only after thorough discussion of the subject at meetings between the Board and representatives of the Cities of Detroit and Windsor, and the Lake Carriers' and Dominion Marine Associations.

An important innovation in the voluntary control program was the use of the radiotelephone in 1953 to enable field staff to notify vessel captains whenever their vessels were observed to be emitting an excessive amount of smoke. Radiotelephone communication has been continued in succeeding navigation seasons.

The smoke emission objectives established for the navigation seasons 1953 to 1958 inclusive are set forth in Table XII-7. It will be noted that over the period of 1953 to 1955 the limitations on smoke emission were made progressively more restrictive.

Table XII-7. Smoke Emission Objectives of the International Joint Commission for Vessels Plying the Detroit River

Navigation Seasons 1953 to 1958

Maximum Number of Minutes of Smoke Emission in Any 30-Minute Period

Objective No.	Type of Vessel	Minutes at Ringelmann No.				
		1	2	3	4	5
	1953					
1	Oil-fired	30	4	0	0	0
2	Spreader-stoker coal-fired water tube boilers	30	30	6	0	0
3	Hand-fired with jet equipment	30	30	9	3	0
4	All other coal-fired	30	30	30	15	0
	1954					
1	Oil-fired and underfeed stoker-fired	30	4	0	0	0
2	Spreader stoker-fired	30	30	6	0	0
3	Hand-fired	30	30	9	3	0
	1955-1958					
1	Oil-fired and underfeed-stoker-fired	30	4	0	0	0
2	Spreader-stoker-fired	30	30	3	0	0
3	Hand-fired	30	30	9	0	0

As a guide to vessel owners who are planning the installation of new fuel burning equipment, the International Joint Commission expects that such vessels will meet the requirements of Objective No. 1. When an ultimate objective has been determined it will probably be in accord with the then existing code of the American Society of Mechanical Engineers; Objective No. 1 is in accord with the present A.S.M.E. Code.

Our experience has indicated that vessels equipped with hand-fired fuel burning equipment cannot, in general, consume fuel with enough efficiency to meet modern smoke abatement codes. Therefore, it is suggested that consideration be given to replacing such equipment with modern fuel-burning equipment as soon as possible.

The yearly objectives will be made progressibely more restrictive as types of equipment and operating methods offer means for compliance.

Consideration will be given to those vessel which fail to comply with these objectives on submission of convincing reasons to the International Joint Commission.

PERFORMANCE OF VESSELS IN RELATION TO SMOKE EMISSION OBJECTIVES

In 1952, smoke emission objectives were directed mainly towards the problem of preventing the continuous emission of No. 4 and No. 5 Ringelmann smoke from hand-fired vessels. This aim was achieved, for the most part, because about 73 percent of the vessels out of a total of 240 with hand-fired equipment were able to comply with their emission objective during all of their passages of the Detroit River. Of 90 vessels equipped with water tube boilers and spreader stokers, 24 vessels or 27 percent complied with their smoke emission objective in all passages of the river. Another 32 or 35 percent of these vessels complied in 81.5 percent of observed passages, but the remaining 34 vessels or 38 percent failed to comply in every observed passage of the river. Most of the steam boiler and diesel equipped oil-fired vessels showed excellent smoke performance in spite of the relatively severe smoke emission limitations set for this vessel class.

In recognition of the fact that the installation of properly designed overfire air and steam jet equipment will aid in the abatement of excessive smoke, a special objective was established for hand-fired vessels with this type of equipment for the 1953 navigation season.

A summary of the number of observed vessels subdivided into classes of various types of firing equipment in relation to compliance with the 1953 smoke emission objectives is shown in Table XII-8. This method of tabulation is a relatively severe measure of compliance since, in order to qualify, the vessels would have to meet their applicable smoke emission objectives in all passages of the Detroit River. Relatively good performance is indicated for oil-fired and diesel equipped vessels; of the 130 in this class, 79 percent of them complied with objective No. 1. Of the 35 vessels in the unknown equipment class, 86 percent complied with Objective No. 1 in all river passages. Stoker-equipped vessels complied with the 1953 Objective No. 2 to the extent of 47 percent out of 87 vessels. Forty percent of 335 hand-fired vessels complied with Objectives No. 3 and No. 4.

To assess the influence of various types of smoke abatement devices on the observed emission of smoke from vessels, a breakdown of equipment on United States vessels was prepared, as shown in Table XII-9. For the purpose of this table it was decided to record as in compliance those vessels which met the 1953 objectives in 66.7% of their passages of the Detroit River. Thus, if a vessel was observed during three passages, it would have to comply with its applicable objective in two of the three trips.

It may be observed that of the one hundred and fifty-eight hand-fired vessels, only 37 percent complied with the 1953 objectives as defined above. The table shows that 64 percent of the hand-fired vessels with jets complied, whereas only 36 percent of those vessels with-

Table XII-8. Smoke Performance in Relation to Objectives for 1953

Vessel Class	Number of Vessels in Each Class	Percent of Vessels Complying With Objectives in all Trips	Applicable Objective
Oil fired and Diesel	130	79	No. 1
Unknown (mainly diesel or oil-fired, including a considerable number of foreign vessels)	35	86	No. 1
Underfeed Stoker	5	40	No. 1
Spreader stoker and other stoker types	87	47	No. 2
Hand-fired	335	40	No. 3 & No. 4
Total	592		

Table XII-9. Summary of Firing Equipment and Smoke Abatement Devices on United States Vessels and Their Relationship to Smoke Performance in 1953

Firing Equipment	Total	Comp.	With Jets				Without Jets				Chemical Additives				Smoke Indicators and Jets			
			Total		Comp.		Total		Comp.		Total		Comp.		Total		Comp.	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Hand	158	37	85	54	38	64	73	46	21	36	22	14	5	23	16[a]	10	13	81
Stoker	89	82	64	72	54	74	25	28	19	26	4	5	3	75	36[b]	40	31	86
Oil	50	92	-	-	-	-	-	-	-	-	-	-	-		9[c]	18	8	89
Diesel	11	100	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] Two vessels without jets not included
[b] One vessel without jets not included
[c] None of these vessels were equipped with jets

NOTE: Comp. - Compliance

out jets complied; thus indicating that jets aid in the control of smoke. Twenty-two or 14 percent of the hand-fired vessels added chemicals with their fuel to attempt to prevent smoke.

Only five or 23 percent of these vessels complied with the objectives, thus showing chemical additives were of little values. Of the sixteen hand-fired vessels with smoke indicators and jets, thirteen or 81 percent complied. These data indicate the value of smoke indicators and jets on hand-fired equipment.

Of the eighty-nine stoker fired vessels, 82 percent complied with the 1953 objectives 66.7 percent of the time. Those stokers equipped with jets showed 74 percent compliance; without jets only 26 percent of the stoker fired vessels complied, thus indicating that jets with stoker fired equipment have definite value. Of the thirty-six stoker fired vessels equipped with smoke indicators and jets, thirty-one or 86 percent complied with the objectives, thus showing the value of jets and smoke indicators as in the case of hand-fired equipment.

Of the fifty oil fired vessels, 92 percent complied, whereas of the eleven diesel driven vessels there was 100 percent compliance.

A similar comparison of the influence of smoke abatement devices on Canadian vessels did not yield data of sufficient value, statistically, because of the relatively few coal-burning vessels equipped with stokers, jets or smoke indicators at this time, and other basic differences in the equipment of the Canadian fleet, including a higher proportion than the U. S. fleet of hand-fired vessels without any smoke abatement devices.

The stricter limitations established for the 1954 navigation season consisted of the elimination of Objective No. 4, previously applicable to hand-fired equipment without jets. Other objectives remained unchanged from 1953. Performance for the 1954 shipping season is shown in Table XII-10. The total number of vessels observed was slightly lower than in 1953. Substantially greater numbers of diesel and oil-fired vessels were recorded, and these conformed with No. 1 Objective about as well as in 1953. Underfeed stoker equipped vessels increased in number from 5 to 12, and compliance dropped from 40 percent to 33 percent. If it is recalled, however, that compliance is defined for tabulation purposes as conformance with the objective for every single passage, the drop is not highly significant, especially as the number concerned is small. The performance of vessels equipped with spreader stokers and other types of automatic equipment improved very markedly; 82 percent compliance with Objective No. 2 for 94 vessels, as compared with only 47 percent

Table XII-10. Smoke Performance in Relation to Objectives for 1954

Vessel Class	Number of Vessels in Each Class	Percent of Vessels Complying with Objectives in all Trips	Applicable Objective
Diesel	24	92	No. 1
Oil Fired.	109	82	No. 1
Unknown (mainly diesel or oil fired, including a considerable number of foreign vessels)	69[a]	77	No. 1
Underfeed stoker.	12	33	No. 1
Spreader stoker and other stoker types	94	82	No. 2
Hand-fired	207	50	No. 3
Total	515[a]		

[a] Twenty-nine U. S. and Canadian Navy and Government owned vessels with unknown firing equipment were not included in this list. However, about 97 percent of these vessels complied with Objective No. 1.

compliance for 87 vessels the preceding year. For hand-fired vessels, the increase from 40 percent compliance with the lenient objectives in 1953 to 50 percent compliance with a more restrictive objective in 1954 is indicative of much improved performance for the season. This may be attributed to more careful attention to recommend firing practices and to the installation of overfire jets in more vessels.

Standards of emission were further restricted for the 1955, 1956, and 1957 navigation seasons. Objective No. 1 remained the same; Objective No. 2, applicable to spreader-stoker-fired vessels, decreased the time of permissible emission of No. 3 Ringelmann from 6 minutes to 3 minutes during any 30-minute period. Objective No. 3 defined for hand-fired vessels a higher standard of performance by eliminating the 3 minutes of No. 4 Ringelmann smoke in any 30-minute period permitted in 1954.

The performance record of Table XII-11 shows that vessels with diesel equipment and unclassified vessels conformed to No. 1 Objective about as well as in 1954. Oil-fired vessels registered a somewhat poorer performance. Underfeed stoker performance in 1955 and 1956 dropped off slightly, as measured by compliance with the unchanged No. 1 Objective. The decrease by 50 percent of permissible emission of No. 3 Ringelmann smoke in Objective No. 2 resulted in a drop in percentage compliance of vessels equipped with spreader stokers from 82 in 1954 to 60 in 1955, and 64 in 1956 and 1957. With respect to hand-fired vessels, whereas half of them complied in 1954 with an objective permitting No. 4 Ringelmann for 10 percent of the time, almost three quarters of them failed to comply with the 1955-1957 objective which prohibited the emission of smoke of density greater than No. 3 Ringelmann.

These year to year comparisons of vessel performance suggest one or two obvious conclusions. One is that diesel equipped vessels, if properly maintained and efficiently operated, could reasonably be expected to comply fully with No. 1 Objective or its equivalent in the existing regulations of Detroit and Windsor. Another conclusion, however, is that, with respect to coal-fired vessels, and, to a lesser extent, oil-fired vessels, measured smoke performance was not adequate in meeting objectives at all times. In order, therefore, to find a more realistic measure of efficiency in minimizing

Table XII-11. Smoke Performance in Relation to Objectives of 1955 - 1957

Vessel Class	Number of Vessels in Each Class			Percent of Vessels Complying with Objectives in all Trips			Applicable Objective
	1955	1956	1957	1955	1956	1957	
Diesel	50	52	79	94.0	90.4	92.4	No. 1
Oil-fired	111	102	118	73.9	68.6	78.0	No. 1
Unknown (mainly diesel or oil-fired, including a considerable number of foreign vessels)	165	78	65	69.3	84.6	90.8	No. 1
Underfeed stoker	15	17	31	26.7	29.4	41.9	No. 1
Spreader stoker and other stoker types	100	99	97	60.0	63.6	63.9	No. 2
Hand-fired	226	243	232	25.7	28.4	31.9	No. 3
Total	658	591	622				

smoke emission, the 1956 data were re-analyzed in terms of a modified definition of compliance. The modification consisted of classifying as in compliance all vessels that in two thirds of their passages of the Detroit River complied with the specified objectives.

An analysis of the smoke observations on the above basis leads to the results shown in Table XII-12. The smoke emission of 492 vessels, or 79 percent, out of a total of 622, was controlled within the limitations of the objectives in 66.7 percent of all vessel passages of the Detroit River. Of the hand-fired coal-burning vessels, 59 percent complied with Objective No. 3 in two-thirds of their observed passages. Again, it is shown that overfire steam and air jets aid in the combustion of fuel because 71 percent of the vessels so equipped were in compliance as compared with only 54 percent compliance for vessels without jet equipment. Spreader stoker equipped vessels complied to the extent of 93 percent with Objective No. 2. In the underfeed stoker class of 31 vessels, 74 percent maintained their smoke emission within the limitations of Objective No. 1. The oil-fired vessels and those in the unknown classification, mainly of foreign registry, were in compliance to the extent of 92 percent. This method of assessing smoke performance did not change substantially the percentage compliance of diesel equipped vessels.

It is not readily apparent as to why a distinction has been made in expected performance between coal-burning vessels equipped with under-feed stokers and those with other types of automatic firing equipment in the International Joint Commission's Objectives. When the underfeed stoker was made available for marine use in 1952, preliminary tests of the equipment on two vessels showed such promise that it was anticipated that combustion of coal with this equipment would be of the necessary high order of efficiency to meet the requirements of the No. 1 Objective.

A detailed analysis of the performance of 31 vessels equipped with underfeed stokers, as shown in Table XII-13, indicates that on the average these vessels were observed to emit No. 2 Ringelmann smoke for only 8 percent of the time. The permissible duration of No. 2 smoke as specified in Objective No. 1 is equivalent to 13.3 percent of the time. The average percentage duration of smoke darker than No. 2 was only 4.9 percent of the time. For 87 percent of the time there was either no visible smoke emission or the density was not greater than No. 1 Ringelmann. Most of the excessive smoke emission was due to the relatively poor performance of six vessels. This poor performance is believed to be caused by improper operation of the firing equipment.

Table XII-12. Smoke Performance of Vessels in 1957 in Relation to Compliance with Objectives in Two-Thirds of Detroit River Passages

Vessel Classification	Total Number	Compliance in two-thirds of passages		Applicable Objectives
		Number	Percent	
Hand-fired without jets	166	90	54.2	No. 3
Hand-fired with jets	66	47	71.2	No. 3
Total Hand-fired.	232	137	59.1	No. 3
Spreader stoker-fired	97	90	92.8	No. 2
Underfeed Stoker-fired	31	23	74.2	No. 1
Oil-fired	118	106	89.8	No. 1
Diesel	79	76	96.2	No. 1
Unknown	65	60	92.3	No. 1
TOTAL (all vessels).	622	492	79.1	

Table XII-13. Underfeed Stoker Fired Vessels, Totals of Trips and Minutes Observed at Specified Ringelmann Number - 1955 Navigation Season

Vessel	Trips Observed	Total Time, Minutes	Minutes at Specified Ringelmann Number						Time at 3, 4, 5 Ringelmann	Average time for trip at more than No. 2 Ringelmann
			0	1	2	3	4	5		
1	11	160	103	38	18	1	0	0	1	0.09
2	3	49	19	8	4	16	2	0	18	6.00
3	10	148	37	19	63	29	0	0	29	2.90
4	3	55	14	14	8	18	1	0	19	6.33
5	4	72	57	15	0	0	0	0	0	0.00
6	9	179	157	18	3	1	0	0	1	0.11
7	4	67	55	12	0	0	0	0	0	0.00
8	10	173	133	21	11	3	4	1	8	0.80
9	8	139	108	20	3	2	6	0	8	1.00
10	5	98	95	3	0	0	0	0	0	0.00
11	5	106	84	22	0	0	0	0	0	0.00
12	9	151	49	57	31	13	1	0	14	1.56
13	1	19	19	0	0	0	0	0	0	0.00
14	1	24	14	10	0	0	0	0	0	0.00
15	3	54	27	14	11	2	0	0	2	0.66
16	6	93	42	19	32	0	0	0	0	0.00
17	1	27	27	0	0	0	0	0	0	0.00
18	5	89	61	3	3	22	0	0	22	4.40
19	7	130	130	0	0	0	0	0	0	0.00
20	5	90	83	7	0	0	0	0	0	0.00
21	5	83	76	3	4	0	0	0	0	0.00
22	9	162	116	40	4	2	0	0	2	0.22
23	4	81	66	11	4	0	0	0	0	0.00
24	6	111	108	3	0	0	0	0	0	0.00
25	8	170	146	2	0	16	6	0	22	2.75
26	11	185	134	33	12	5	1	0	6	0.55
27	11	202	142	28	25	7	0	0	7	0.64
28	7	146	110	18	18	0	0	0	0	0.00
29	9	165	112	53	0	0	0	0	0	0.00
30	8	158	85	52	13	5	3	0	8	1.00
31	2	37	22	5	9	1	0	0	1	0.50
	190	3423	2431	548	276	143	24	1	168	
Percent of time at specified Ringelmann number			71	16	8.1	4.2	0.7	0	4.9	

It is evident from the above analysis that performance of the underfeed stoker in strict conformance with No. 1 Objective is definitely inferior to that of oil-fired or diesel equipment. On the other hand, with a more lenient interpretation of performance, the smoke emission of the majority of vessels equipped with underfeed stokers may be considered as being within the limitations of existing Windsor-Detroit regulations.

Vessels equipped with diesel or oil-firing, if the equipment is properly maintained and operated, may reasonably be expected to comply fully with the No. 1 Objective, or the Windsor-Detroit regulations. Where coal is the source of power, the smoke performance of spreader stokers is, in general, similar to that of underfeed stokers. Consequently, with a liberal interpretation of the above regulations, vessels so equipped should be capable of satisfactory pollution control. The main problem is the hand-fired vessel. In order to maintain control emission in a majority of the hand-fired vessels such that they would comply with the Ringelmann Objective No. 2, it would be necessary to convert these vessels to automatic stoker-firing, or to convert them to oil-firing; or employ experienced firing personnel with sufficient training and pride in their work such that constant efforts would be maintained to control smoke emissions.

REMEDIAL MEASURES FOR HAND-FIRED VESSELS

It is clear from the foregoing that the hand-fired vessel constitutes the main problem in the control of atmospheric pollution from lake shipping. The vast majority of hand-fired vessels on the Great Lakes are equipped with Scotch marine boilers. For this type of vessel the most satisfactory installation for use with coal as fuel is the underfeed stoker. Conversion to oil-firing would represent an alternative solution to the problem of the hand-fired vessel. Most of the larger vessels containing water tube boilers and fired by coal are equipped with spreader stokers. Few such vessels are fired by hand. Essentially, therefore, the economics of satisfactory remedial measures are concerned with the costs of conversion of Scotch-marine boilered vessels to either underfeed stoking or oil-firing.

In order to make reasonable recommendations to the International Joint Commission, the Technical Advisory Board has endeavored to gather available information from several sources on studies of the costs of installing underfeed stokers and oil burners in lake vessels formerly fired by hand. The facts presented here do not represent an exhaustive study of all the intricate and complex facets of the subject. What is contained herein, however, is a fair evaluation of the more salient points. Most of the economic figures are equally applicable to both American and Canadian fleets, though certain aspects, as labor savings and the influence of the St. Lawrence Seaway, may differ in emphasis and in detail. It should be recognized also that savings in labor costs, which constitute the greatest economy following conversion, form a part of income and are, therefore, taxable.

As concerns Detroit River shipping, the economics of conversion apply to approximately 200 hand-fired vessels equipped with Scotch marine boilers. Of the 200 vessels, some belong to the 2,000 to 3,000 ton "canaler" type, but the proportion of these to total shipping is somewhat lower in the Detroit River than in the lower reaches of the Great Lakes system. The problem of converting "canalers" or replacing them with vessels of greater cargo capacity is, therefore, less acute in the Detroit River than in the Lower Lakes.

The types of automatic firing discussed here are underfeed stokers and oil burners. The economic aspects covered are: cost of units and installation, cost of operation, cost of maintenance, performance, labor savings, potential savings and amortization of capital expenditure.

Underfeed Stokers

Since the 1951-1952 lay-up, 37 hand-fired vessels with Scotch marine boilers have been converted to underfeed stoker firing. Performance as related to a modified No. 1 Objective has been good, and it may be assumed that the municipal smoke abatement codes of the Detroit-Windsor area would be applicable.

Original costs for stoker, automatic controls, fuel handling equipment and installation in 1955 were about $60,000 to $65,000 for a six-furnace vessel, and about $45,000 to $50,000 for a four-furnace vessel. Estimates of current costs run as high as $100,000 for a six-furnace vessel.

Operating costs, aside from that of labor, show some advantage for underfeed stoking as compared with hand-firing. Fuel costs per ton are about the same for both, but underfeed stoking reduces coal consumption by as much as 9 to 10 percent, resulting in a yearly saving per vessel of 250 to 800 tons of coal or $3,000 to $5,000. Also, with the steadier steam pressure resulting from underfeed stoking a three percent increase in speed is possible on the average. A four to five percent increase would be sufficient to permit one additional trip per season, worth something on the order of $10,000 to $15,000. Some, but not all, underfeed stokered vessels would, therefore, be able to realize this potential advantage.

Estimates of maintenance costs vary considerably, and the safest assumption is that they would be about the same for hand-fired vessels. In either case the yearly cost is of the order of $1,000 and differences are insignificant.

With regard to labor savings, the normal complement of six firemen and coal passers on a six-furnace hand-fired vessel can be reduced to three on conversion to underfeed stoking. Some four-furnace vessels carry a firing crew of six for hand stoking, others only three. The possible reduction in crew personnel is, therefore, either three or none. A reduction in number of crew by three effects a saving of $10,000 a year in wages alone. To this can be added the cost of bonuses, food, hospitalization, etc., and the total potential saving is estimated to be about $15,000 a year.

Oil Burners

Quite a number of vessels have been converted from hand-firing to oil-burning, and many of the newly commissioned vessels in recent years are fitted with oil burners.

Performance as related to No. 1 Objective has been good, and full compliance with municipal smoke abatement codes is a reasonable requirement.

The investment for burners, automatic controls, fuel storage and installation varies from $80,000 to $100,000 for a six-furnace vessel.

Fuel costs are, of course, higher for oil-fired vessels. A fair estimate is that oil costs about 20 percent more than coal for a season's requirements. This represents an increase of $15,000 to $20,000 in a season's fuel cost.

Several factors offset the increase in fuel cost. Most vessels on conversion are able to get one extra trip per season worth $10,000 to $15,000 by reason of an increased average speed; some vessels are said to make two extra trips. Also, a 50 percent reduction in fuel bunker space permits a corresponding increase in cargo space, which, in one case at least, was said to be worth more than $20,000 a season.

Maintenance costs about $500 a year less for oil-burning equipment than for coal-burning equipment. However, there might be added to this relatively low figure a figure to take into account both a longer boiler life and decreased boiler repairs. Longer boiler life is attributable to the less corrosive action of the combustion products of oil, and it is said that several vessel owners have had oil-burning equipment installed primarily to prolong boiler life. Boiler replacement and repairs are very expensive items. One Canadian company has reported a conversion of four Scotch marine hand-fired boilers to two water-tube oil-fired boilers at a cost of $270,768.

Labor savings are very substantial for oil-fired vessels because one oil wiper is carried in place of three coal passers, at a savings of $10,000. For six-furnace vessels, therefore, labor savings run about $25,000 or more. On vessels with four furnaces, two coal passers are always eliminated, a saving of $10,000, and on those carrying six firemen another three men are eliminated. Labor savings thus run from $10,000 to $25,000.

An intangible advantage over hand-firing, which refers particularly to oil-firing, but to a considerable degree to stoker firing, is the great improvement in working conditions. In recent years, the difficulty of hiring and keeping firing crews has increased greatly. Where automatic firing is in use a better class of crew is attracted, and labor turnover is reduced.

It is clear from Table XII-14 that savings in labor costs and increased profits resulting from extra trips are such that, for vessels of sufficient cargo carrying capacity, conversion to underfeed stoking or oil firing can reasonably be expected to pay for itself in a reasonable number of years.

The data given above on underfeed stokers and on oil burners are recapitulated in Table XII-14 as follows:

Table XII-14. Recapitulation of Data on Conversion of Six-Furnace Hand-Fired Vessels to Automatic Firing.

Underfeed Stokers	
Original cost.	$80,000 to $100,000
Maintenance	About as for hand-firing
Speed.	About 1/4 to 1/2 m.p.h. greater
Fuel saving	$3,000 to $5,000 per year
Labor saving.	$15,000 per year
Oil Burners	
Original cost.	$90,000 to $100,000
Maintenance	Saving of about $500
Speed	About 1/4 to as high as 1 m.p.h. greater
Labor saving.	$25,000 per year
Additional cargo carried	$10,000 to $20,000 increased revenue per year
Boiler replacement and repair.	Unestimated, but substantial savings.

For vessels of small carrying capacity, designed within the limits set for navigating the St. Lawrence River canals, the above considerations do not apply because they only carry one man per shift to fire furnaces so that no labor saving is possible after conversion. These "canalers", with a carrying capacity of 2,000-3,000 tons, fill an economic need in present circumstances; some seven or eight of them are required to keep a single large Upper Lakes bulk carrier in operation, and in the past they have been a significant factor in the Great Lakes shipping economy, particularly with respect to the Canadian fleet. After the completion of the St. Lawrence Seaway, however, their significance in the economy will be greatly reduced, and it is expected that they will be withdrawn from this service, perhaps within a few years, or replaced by vessels better adapted to the changed operating conditions. Excessive smoke emission by "canalers" is here considered, therefore, an interim problem, for which no economical remedial measures are available and which will disappear in a few years through force of circumstances.

GREAT LAKES AIR POLLUTION ABATEMENT PROGRAM (GLAPAP)

The following section was prepared by the GLAPAP.

The Great Lakes Air Pollution Abatement Program is a voluntary cooperative research and development program organized and supported by Bituminous Coal Research, Inc., the national research agency of the coal industry; the Lake Carrier's Association, representing operators of Great Lakes bulk cargo vessels of the United States; the Dominion Marine Association, representing lake vessel owners of Canada; and the Coal Producers Committee for Smoke Abatement. The program was organized in July, 1950, at which time an Engineering Advisory Committee, representing the contributing sponsors, was selected to plan and supervise the program.

The general objectives of the program have been development of equipment and methods to reduce stack emission to accepted levels, general improvement in the economic position of bituminous coal for bunker fuel application, assistance to vessel owners in the adoption of equipment and methods developed and recommended under the program and the education of lake vessel personnel in proper combustion and firing methods.

One of the first undertakings under the program was the collection and tabulation of complete data on the fuel burning equipment installed on each Great Lakes vessel. Since then, an effort has been made to keep the data current. The tabulation disclosed the vessels needing attention and has indicated the improvements accomplished.

Early in the program bunker fuel standards were established as to the size and quality of coals acceptable for both hand-fired and stoker-fired vessels. (Appendix A) The specifications were made known to all concerned with the production, transportation, supply and use of coal for lake vessel consumption. Forms for reporting unsatisfactory fuel were prepared and procedures for handling complaints were established. Full cooperation has been given in this part of the program and satisfactory fuel has been supplied.

Field performance observations were carried out on many vessels by teams of competent combustion engineers for the purpose of establishing an experience background of the air pollution problem as indicated by the smoke performance of typical classes of lake vessels. Analysis of the reports made by these teams helped in setting up a procedural program and resulted in immediate improvement on many vessels.

Following extensive on-the-job experiments, a bulletin was issued, describing the proper installation of overfire jets on vessels equipped with water-tube boilers and spreader stokers. The bulletin was used as the basis for design of a number of installations that have given excellent smoke performance results.

Realizing that hand-fired Scotch marine boilers presented a big problem, the Engineering Advisory Committee obtained a boiler of this type and had it set up on shore. Battelle Memorial Institute, a well known research and development organization, was employed for research in the use of jets and the development of proper firing procedures. The result of this work was published in a bulletin in 1953 and subsequently the recommended device was installed in many vessels. The jets have proven helpful in permitting the operation of the hand-fired Scotch marine boiler with reasonably satisfactory smoke performance.

The development of an underfeed stoker for the conversion of hand-fired Scotch marine boilers was encouraged and subsequently such equipment was given general approval. To date 43 installations have been made in Great Lakes vessel and more are slated for the future. The underfeed stoker does enable vessels with Scotch boilers to meet reasonable standards for smoke emission but for economic reasons not all vessels can be expected to install this type of equipment.

Figures were obtained and furnished the Technical Advisory Board on the economics of converting Scotch marine boilers from hand-firing to either underfeed stokers or oil.

The instruction of vessel personnel in correct firing habits and procedures has always been given top consideration in improving the smoke emission of Great Lakes vessels. Combustion experts have visited the ships to observe and establish improved firing methods. Lectures have been given at schools conducted by both the Dominion Marine and Lake Carriers' Associations. Manuals and instruction courses have been made available to vessel personnel.

Since 1953 GLAPAP has underwritten a program in which trained professional observers of the Technical Advisory Board notify the master immediately by radiotelephone when a vessel is seen to be not conforming to smoke emission objectives set up for the Detroit River area. Such on-the-spot reports have been effective in securing improved vessel performance. The program is still in effect.

The annual reports made to the International Joint Commission by the Technical Advisory Board have been reproduced for the last three years and distributed to vessel operators and the ships. Since these reports showed the smoke performance of each vessel, they afforded a means of comparing vessels with the same type of equipment and pointed out the vessels to which priority should be given in remedial measures.

The accomplishments of the GLAPAP have been due in a large measure to the cooperation between vessel owners, suppliers of vessel fuel and vessel operating personnel. The Marine Committee of the Air Pollution and Smoke Prevention Society of America, Inc., enforcement agencies in the Great Lakes ports; and equipment manufacturers have contributed much to the effort. The Technical Advisory Board to the International Joint Commission has been exceedingly helpful. The interest of vessel operators and their willingness to adopt recommended equipment and procedures have been most encouraging. All interested groups have worked together toward a common goal.

Just what has been accomplished can best be shown by reports compiled by the Technical Advisory Board following observations made in the Detroit River area over the past eight years. The figures given below in Table XII-15 are taken from those reports.

It is evident from the above figures that not all Great Lakes vessels are presently able to meet the codes established in many cities but it

Table XII-15. Smoke Performance of Vessels Plying the Detroit River.

Observations Recorded in Percent of Time			
Year	Clear and No. 1 Ringelmann	No. 2 Ringelmann	No. 3, 4, & 5 Ringelmann
1950	36.5	12.8	50.7
1951	47.1	18.1	34.7
1952	49.4	19.4	31.1
1953	59.8	12.7	27.5
1954	77.5	10.6	11.8
1955	75.5	13.0	11.4
1956	69.2	17.4	13.4
1957	78.4	10.8	10.8

is also apparent that the number of such vessels not conforming to the minimum smoke emission standards of these codes has been greatly reduced during the last few years. The ones still needing attention have Scotch marine boilers. They are the older vessels for which the great expense of reboilering cannot be justified. They will continue to disappear from the scene because of age and inefficency and thus will not long remain a problem.

GLAPAP continues in existence and will maintain its efforts to reach complete attainment of its objectives.

This completes the submission of the GLAPAP organization.

APPENDIX A

Hand-Fired Vessels

"Bunker fuel for hand-fired vessels is restricted to double screened coal sizes that will meet the following size and quality specifications:

The preferred vessel fuel for hand-firing is 4" x 1-1/4" Egg with not over 8% ash. Top sizes up to 6" and 7" are acceptable with a minimum bottom size of 1-1/4". For 3, 4, and 5" top sizes the minimum bottom size is 3/4".

Excessive undersize, (screening or handling) high moisture and ash above 10% are factors contributing to poor performance and economy. Coals so classified will be rejected as unsuitable for use on hand-fired vessels."

Stoker-Fired Vessels

"Bunker fuel for spreader stoker-fired vessels is restricted to bituminous coal that will meet the following size and quality specifications:

The preferred vessel fuel for stoker-firing is double-screened stoker coal with a top size range of 3/4" to 1-1/2" and a bottom size range of 28 mesh to 5/8", with not over 10% ash. Nut and slack sizes are acceptable with the same range of top sizes, provided the fines under 3/8" and 1/8" respectively, do not exceed 50% and 30% of the total.

The reduction of fines, uniformity and quality improvement resulting from double-screening and/or mechanical cleaning contribute to improved performance and economy. Coals with more than 5% oversize, over 12% ash and surface moisture exceeding 5% will be rejected as unsuitable for use on stoker-fired vessels".

Chapter XIII

DISCUSSION OF FINDINGS AND RECOMMENDATIONS

SUMMARY OF BACKGROUND INFORMATION

DESCRIPTION OF THE DETROIT RIVER AREA

The area considered under the Reference contains the cities of Detroit and Windsor and a number of other municipalities located in the Detroit River area. The population of this area is as follows:

	Estimated Population[a]
Detroit	1,902,000
Other communities in the U. S. . .	1,242,790
Windsor	120,049
Other communities in Canada . . .	97,101
Total	3,361,940

[a] Canada - 1951
United States - 1955

The terms of the Reference are considered to embrace an area extending about 15 miles inland on either side of the 31-mile length of the Detroit River. The area contains the third highest concentration of industry in North America with a total of about 6,400 manufacturing establishments, of which about 5,950 are located in the United States and approximately 450 in Canada. Although the automotive industry occupies a dominant position in both Detroit and Windsor, there are large establishments which produce primary metals such as steel, pig iron and non-ferrous metals, fabricated metal products, electrical and other machinery, chemicals and allied products, rubber goods, petroleum and coal products, meat products, malt liquors and beverages. The region is also highly developed for residential, agricultural and recreational purposes.

The Detroit River carries Great Lakes vessel traffic that involves total passages of about 28,000 and the transport in a normal navigation season (April - November) of over 100,000,000 short tons of cargo consisting principally of iron, ore, coal, limestone, and grain.

TOPOGRAPHY AND CLIMATOLOGY

For the most part, the land in the Detroit River area is flat and rises gradually on both sides of the river. On the United States side the elevation above sea level along the river varies from 575 to 590 feet; on the Canadian side it is almost uniformly 575 feet. The elevation on the Canadian side gradually increases away from the river to 600 to 625 feet, east of Windsor and Sandwich. On the United States side, an elevation of 600 feet is reached inland along a line approximately parallel to the river and this elevation increases to 650 feet about half way across the study area. At the western and northern limits of the area the elevation rises more sharply to heights of 800 to 900 feet.

The climate of the Detroit River area is basically a continental type but the waters of the Great Lakes exert a modifying influence. The area lies in the mid-latitude belt of a general west-to-east flow of air during all seasons of the year. This westerly flow is associated with frequent surges of fresh air masses in the form of a succession of cold frontal passages at all seasons.

The climatology is, in general, favorable for the dispersion of air contaminants. The general features of the circulation bring a succession of changing pressure systems and air masses across the area, and the topography does not favor any localized areas of stagnating air flow.

There are transitory periods during which conditions favorable for the accumulation of air contaminants near the ground can develop, principally during night hours in the warmer portion of the year. However, there is little evidence that such conditions persist for any extended period.

TRENDS RELATIVE TO POLLUTION FROM LAND-BASED SOURCES

The Detroit-Windsor area is a rapidly expanding metropolitan region. The Detroit area ranked third among the eight largest metropolitan areas in the United States in percentage of population increase in the 1940-1950 decade, exceeded only by Los Angeles County and the San Francisco Bay Area. A similar growth took place in the greater Windsor Area. It is anticipated that this rapid growth will continue with an estimated population in the Detroit-Windsor area of about 4, 250, 000 in 1960, or about a 31 percent increase over the 1950 population.

The substitution of other fuels for solid fuels will tend to reduce the particulate pollution discharged to the atmosphere, and the trend is to substitute natural gas for coal in space heating. A trend which will tend to worsen the pollution situation is the increased use of automotive fuels. The number of automobiles, the number of automobiles per capita, and the automobile horsepower has increased markedly over the years, resulting in a corresponding rise in the volume of exhaust gas products discharged to the atmosphere.

It is anticipated that continued growth of population, industry, commerce and transportation will result in a corresponding rise in the pollution load of the atmosphere from such major sources as combustion of fuels, blast furnaces and steel mills, automotive vehicles and equipment, petroleum refining, industrial chemicals (including manufacture of cement), gasoline and oil storage, concrete products and paving mixtures, and from miscellaneous manufacturing operations involving grey iron furnaces, foundries, non-metallic mineral products, solvents and many other products. New pollution problems may arise in connection with future use of atomic energy for generation of electric power and other purposes.

To counteract this trend towards increased pollution of the atmosphere, many sources of effluents will have to be rigorously controlled. Greater removal of particulate emissions and by-product recovery of various gaseous waste products, undoubtedly, will become necessary.

For the most part, the technical knowledge is available to control atmospheric pollution at the source in combustion and industrial operations. The extent of such control or elimination of waste products is now largely a matter of economics. However, certain activities of the public, including the increasing use of automotive vehicles for transportation, have contributed substantially to the pollution problem in some large cities. The combustion products from gasoline and diesel engines contain unburned hydrocarbons, carbon monoxide, oxides of nitrogen, sulfur compounds, aldehydes, organic acids and other compounds that may attain objectionable concentration levels either under adverse meteorological conditions or in heavy traffic. This problem is likely to become more acute with the continued growth of large metropolitan areas. The control of such exhaust gas waste products by improved engine design, controlled fuel injection, catalytic combustion devices, changes in fuel and other methods has occupied the attention of technical committees in the automotive industry in Detroit and some research organizations in California and elsewhere within the last few years. A complete solution is not yet in sight.

Studies in the Los Angeles area and elsewhere have demonstrated that photochemical reactions may take place in the atmosphere in sunlight between certain types of hydrocarbons, or their oxidized products, and oxides of nitrogen to create ozone, form haze or smog, and produce eye irritation, accelerate the deterioration of rubber goods and cause damage to certain types of vegetable crops. Eye irritation has been reported on occasion in the Detroit-Windsor area, in the Sarnia-Port Huron area, and in San Francisco, among other cities of North America. There is reason to believe that with the continued increase in automotive vehicles in the greater Detroit-Windsor area, the above effects of exhaust gas may become a matter of major concern unless successful control measures are developed.

The trend in governmental control efforts is towards the organization of metropolitan, regional, county or other groups covering a wider area of activity than the purely local level.

Activity on the State and Provincial level of government is increasing. Control of emissions is being expanded in many areas to embrace all types of air contaminants and not merely smoke, fly ash and soot from fuel-burning equipment.

Federal activities in the United States in the field of air pollution have been greatly expanded since the enactment of Public Law 159 by the 84th Congress in July of 1955. A rather extensive program of research and technical assistance to states and communities is under way. However, no control activities are contemplated since, in the Act, the Congress declared the policy of preserving and protecting the primary responsibilities and rights of states and local governments in controlling air pollution.

TRENDS AFFECTING POLLUTION FROM VESSELS

The future growth of vessel traffic on the Great Lakes and on interconnecting waterways such as the Detroit River is linked intimately with the effects of the opening of the St. Lawrence Seaway. The St. Lawrence Seaway power and navigation project, scheduled for completion in 1959, will provide for movement of vessels with a 27 foot draft from the Atlantic Ocean to the lower Great Lakes. It is probable that the most important change to water transportation resulting from this project will be to allow the passage of large bulk freighters of the Great Lakes into the lower St. Lawrence, and vice versa.

A large increase in marine transportation is anticipated after the St. Lawrence Seaway is opened. In the early years after opening of the Seaway, most of the expected traffic increase will be of types which can be handled more economically in lake-type bulk carriers rather than ocean vessels. Within the first year after completion of the Seaway, it has been estimated that about 32,000,000 tons of cargo will move through this waterway, of which approximately 26,000,000 tons will consist of grain, iron ore and coal, carried mainly in lake-type vessels, and about 6,000,000 tons will constitute "general cargo," most of which will move in ocean-going vessels.

After a development period, the Seaway commerce on the upper St. Lawrence and the lower Great Lakes is expected to reach a level of about 45,000,000 to 50,000,000 tons or more per annum. Approximately 75 percent of this commerce will ply the Great Lakes, including the movement from Labrador of 20,000,000 tons of iron ore not presently being transported on the Great Lakes.

Traffic on the Detroit River, a vital connecting waterway, will increase to a corresponding degree. The Detroit Metropolitan Area Regional Planning Commission has prepared estimates of the future increase in tonnage of cargo handled at the Port of Detroit. These estimates indicate that river vessel traffic will be 80 to 110 percent greater in the year 1960 and about 200 to 270 percent larger in the year 1956 as compared with tonnage loads in 1952.

These increases in vessel traffic will undoubtedly result in an increase in pollutants discharged to the atmosphere. The need for conscientious efforts to reduce such emissions to the practical minimum, with particular emphasis on the control of excessive smoke, is therefore apparent. However, two factors which will tend to lessen the pollution load should be noted. One is the gradual conversion of hand-firing coal-burning vessels to automatic stoker or oil firing. The other is that nearly all vessels constructed in the last few years have been equipped with either oil-fired boilers or diesel engines and this type of construction is expected to set the pattern for future building of ships for use on the Seaway and Great Lakes System.

DISCUSSION OF FINDINGS

POLLUTION OF THE ATMOSPHERE

The atmosphere under reference is being polluted on both sides of the boundary to an extent which is detrimental to the communities along the Detroit River.

Comprehensive studies have been made of the levels of dustfall or rates of deposition of coarse particulate matter, aerosols or fine particulates suspended in the atmosphere, sulfur dioxide, and other contaminants. The extent of atmospheric contamination has been studied at continuous sampling stations over long periods of time and also in area-wide networks of stations over shorter periods. In many places there exist relatively high levels of contaminants, particularly during certain periods of unfavorable meteorological conditions.

The atmospheric concentrations of particulate matter and sulfur dioxide are influenced by prevailing meteorological conditions that cause variations of both a diurnal and seasonal character. Certain weather factors are associated with fluctuations in particulate pollution levels. The most important of these are the wind speed and direction, the stability of the atmosphere, the 24-hour temperature change, the duration of precipitation, and the time of passage of a cold air front.

The environmental data have been utilized to distinguish between areas of high, intermediate and low pollution. The most heavily polluted areas lie close to the Detroit River and within the zones surrounding major industrial operations. Rates of dust deposition are about two to three times higher in industrial-commercial districts than in residential sections of Detroit and Windsor. Annual mean dustfall for all types of areas in Detroit, in terms of insoluble solids in tons per square mile per month, has increased from about 52 in 1946 to about 72 in 1953. In Greater Windsor, over a period of about 4 years from 1951 through 1954, the mean range has varied from 66 to 105 tons per square mile per month in the heavily polluted areas and from about 37 to 66 in the residential sections.

Suspended particulate matter samples from the atmosphere of Greater Windsor, in area-wide surveys for six-week periods, carried out in 1951 and 1952, indicated a two- to three-fold difference in pollution loading at the high pollution stations in comparison with those collected at low pollution stations. Similar surveys in Detroit in the same years yielded comparable differences between the lowest and highest pollution sampling stations, although the absolute levels of particulate pollution were considerably higher in Detroit than in Windsor.

A two and one-half year study of atmospheric particulate pollution levels in Windsor and the town of Harrow, Ontario, located about 20 miles south of Windsor, during 1953 to 1955, indicated that the atmosphere of the Windsor high pollution area contained monthly mean loadings of about two to six times the mean loadings at Harrow.

Pollution by sulfur dioxide has been investigated over a five-year period at various places in Greater Windsor, at the village of McGregor, 15 miles from the Detroit River, at the town of Harrow and for long periods of time in the United States portion of the study area. In the industrial areas of Windsor the mean concentrations over this period were about five to more than seven times the means at sampling stations 15 to 20 miles distant from the Detroit River. The maximum monthly mean in the industrial part of Windsor was about ten times the maximum monthly mean at Harrow, Ontario. Mean sulfur dioxide levels in the Detroit high pollution area were about twice as high as in the Windsor high pollution area.

TRANSBOUNDARY FLOW OF POLLUTION

There is a transfer of pollution from each side of the boundary to the other, the most serious effect involving the flow of pollution from the River Rouge-Zug Island area of the United States to the Canadian side of the Detroit River.

Air-borne particulate pollution was measured at a network consisting of six pairs of sampling stations at opposite points along both sides of the Detroit River from the vicinity of the southern part of Grosse Ile to the eastern end of Belle Isle. The air pollution measurements were correlated with meteorological observations in the form of wind rose analyses. A considerable amount of particulate pollution was determined to be passing from the River Rouge-Zug Island area in the United States to the Ojibway area in Canada. In the Ambassador Bridge area, and in the Wyandotte (U. S.)-LaSalle (Canada) area, a slight movement of particulate pollution from the United States to Canada was measured, while near the southern end of Grosse Ile a slight movement of particulate pollution from Canada to the United States was noted.

SOURCES OF POLLUTION

Vessels plying the waters of the Detroit River contribute seriously to pollution in the Detroit River area particularly for short intervals of time over relatively small areas, but other major sources involving industrial, domestic and land transportation activities contribute to a much greater extent when average pollution levels over the entire study area are considered. Although the voluntary vessel smoke control program has resulted in a great improvement of smoke conditions due to vessels on the Detroit River, the excessive emission from about 25 percent of the vessels, nearly all in the hand-fired, coal-burning class, is still a source of detrimental pollution.

The Technical Advisory Board has been assisted greatly in the voluntary smoke control program by the Department of Buildings and Safety Engineering, Bureau of Smoke Inspection and Abatement, of Detroit, the Air Pollution Control Department of Windsor, other municipalities along the Detroit River, the Lake Carriers' Association, the Dominion Marine Association, Bituminous Coal Research Inc., and the Coal Producers Committee for Smoke Abatement. The latter four organizations representing vessel owners and coal producing interests established the Great Lakes Air Pollution Abatement Program (GLAPAP) in 1950 to assist the International Joint Commission and its Board in the control of the vessel smoke problem. An Engineering Advisory Committee was organized under GLAPAP to study remedial measures, investigate devices to improve combustion and establish specifications for coal used on Great Lakes vessels. The associations representing vessel owners and operators distributed combustion manuals and other educational pamphlets to officers and other personnel in the various fleets and conducted training schools for firemen and others employed on the vessels to promote smokeless combustion of fuels. They also financed radiotelephone communications between smoke observers and vessel captains.

In 1952 and subsequent years, the International Joint Commission adopted the policy of establishing smoke emission standards or "Objectives," as recommended by its Technical Advisory Board, to restrict smoke within specified limits for various types of fuel-burning equipment. These emission objectives have been made more restrictive, progressively, as continued advances in engineering research and development have made available the necessary equipment and practices to improve combustion and to offer means for compliance with stricter objectives.

The progress in abatement of smoke conditions on the Detroit River has been most notable in the three navigation seasons from 1952 to 1954, as shown in Table XIII-1 compiled from data based on Ringelmann Chart observations of approximately 500 to 650 vessels in passages through this waterway in each navigation season.

The hard core of the vessel smoke problem has been reached within the last few years. The great majority of vessels equipped with automatic firing installations such as diesel engines, oil-fired furnaces, underfeed and spreader stokers have shown satisfactory progress in smoke abatement and will have little difficulty in meeting the emission requirements of modern air pollution control regulations. Smoke emission from about 25 percent of the vessels of the Great Lakes fleets operating on the Detroit River is still excessive. Nearly all the vessels in this unsatisfactory class are powered by hand-fired coal-burning boilers and require conversion to automatic firing methods or other fuels before further progress in smoke abatement can be achieved.

About 43 percent of the Canadian Great Lakes fleet are hand-fired coal-burning vessels. In the United States fleet this class represents about 37 percent of the vessels. A large proportion of the Canadian hand-fired fleet consists of canal-sized vessels of approximately 1,600 to 2,400 tons. Such vessels were designed within the limits prescribed for navigation of the St. Lawrence River Canals and perform a vital

Table XIII-1. Smoke Emission from Vessels in Percent of Observed Time

Year	Percent duration clear conditions & No. 1 Ringelmann	Percent duration No. 2 Ringelmann	Percent duration Nos. 3, 4, & 5 Ringelmann
1950	36.5	12.8	50.7
1951	47.1	18.2	34.8
1952	49.4	19.4	31.2
1953	59.8	12.7	27.5
1954	77.6	10.7	11.8
1955	75.5	13.0	11.4
1956	69.2	17.4	13.4
1957	78.4	10.8	10.8

service in the forwarding of cargoes carried by the upper lake vessels to the Port of Montreal and other lower St. Lawrence ports.

The varied nature of the extensive land-based industrial and commerical operations, the magnitude of transportation traffic on land as well as domestic fuel-burning and other activities of the public give rise to large quantities of many atmospheric contaminants. These consist of smoke, soot, fly ash and other particulate matter, sulfur dioxide, oxides of nitrogen, aldehydes and other gaseous contaminants and vapors.

Total domestic, commercial and industrial consumption of solid fuel in land-based installations, which was formerly at the level of about 15,000,000 to 16,000,000 tons annually, has declined to 12, 244,000 tons annually in 1954-1955, due to the increased use of natural gas. The approximate solid fuel consumption by vessels during passages of the Detroit River in an average navigation season has been estimated to be about 108,000 tons. Over the 8-month navigation season this fuel consumption by vessels represents only about 1.5 percent of the total solid fuel burned in the area in land-based industrial, commercial and domestic furnaces. However, the land-based sources are distributed over a comparatively large area within the approximately 900 square mile region under study, whereas the smoke and fly ash deposition from vessels is concentrated in a narrow belt adjoining the Detroit River. Data in Table XIII-2 indicate the total emissions to the atmosphere in this area of gases and vapors and particulate waste products through operations of industry and commerce, and the general public.

EFFECTS OF POLLUTION ON VEGETATION

Injury to vegetation has been noted on both sides of the International Boundary in proximity to a few land-based sources of local contamination.

Present knowledge of the effects of urban air pollution on vegetation is far from adequate. Most studies of this subject have dealt with special instances of acute emission of a single toxic component such as sulfur dioxide or hydrogen fluoride. The presence in the urban atmosphere of a considerable variety of particulate and gaseous pollutants tends to complicate the pattern of nonspecific symptoms and plant damage. A similar, if not identical, syndrome may be produced by disease, insect injury, and other factors. In the case of nonspecific complaints of poor growth in urban areas, the influence of such factors as inadequate soil moisture, poor drainage, nutritional imbalances and other soil conditions and cultural practices may contribute to the poor growth.

A survey team made general observations of vegetation throughout the study area, and particularly in the vicinity of probable sources of pollutants, in an attempt to determine the nature and extent of injury. Considerable caution has been exercised in the interpretation of the data of the survey in view of the difficulties described above. It was concluded that there is no unequivocal indication of an over-all repressive effect on the vegetation of the region due to air pollution. Where symptoms of injury to vegetation, presumably attributable to air pollution, were found they were limited generally to a few susceptible species in the immediate vicinity of a large probable source of the pollutant. Careful examination of the plants usually suggested that the injury arose from a specific pollution incident or combination of circumstances of relatively short duration (a matter of hours perhaps) rather than from a long-term chronic ex-

Table XIII-2. Estimated Total Emissions to the Atmosphere of Detroit River Study Area[a]

(Data in tons per day) as of 1956

Pollutant	General Public	Industry & Commerce	Total
Aldehydes.	40	10	50
Nitrogen Oxides (as NO_2).	250	190	440
Acids (as Acetic). .	230	280	510
Organics[b].	1060	600	1660
Sulfur Oxides (asSO_2)	440	650	1090
Gases (not specified)	0	250	250
Total Gases	2020	1980	4000
Solids.	230	~~1040~~[c] 540	~~1270~~ 770

[a] Does not include CO and CO_2.

[b] Includes gasoline and other solvents.

[c] Does not include particulate matter discharged from use of coal in blast furnaces, steel furnaces, iron foundries, or steel foundries.

posure. The survey clearly indicates the need for much further work on the response of vegetation to all the factors of an urban environment before the effects of the air pollution factor can be delineated without compromise.

EFFECTS OF POLLUTION ON HEALTH

The possible effects of air pollution on health were investigated in a two-year pilot study. Insofar as the health status of the people in selected areas was measured by the methods used in this study, no relationship was observed between existing levels of air pollution and health. However, the findings may be regarded as inconclusive rather than negative. The effects may be too small, with the pollution differentials prevailing in the areas studied, to be apparent with the relatively crude health measurements employed. A further possibility is that limitations inherent in the methodology may have obscured an effects present. Clearly, the elucidation of the relationship between atmospheric contamination and the health status and sickness experience of exposed populations requires further study.

OTHER EFFECTS OF POLLUTION

Pollution reduces visibility and solar illumination. There is also an adverse effect on property through reaction with gaseous pollutants and deposition of particulate contaminants.

A parallel study of daylight illumination in the City of Windsor and at Harrow, Ontario, about 20 miles south of the Detroit River, has shown that the illumination at Windsor was reduced by the presence of aerosol particles that attenuate incoming solar radiation by reflection, scattering and absorption of light. The measurements at the town of Harrow were also affected by the presence of particulate pollution; for example, when winds were from the northwest, a substantial fraction of the pollution found in Harrow very probably originated in the Detroit - Windsor area. However, when the monthly mean illumination at Windsor was expressed as a percentage of that at Harrow, the monthly values ranged from a low of 80 percent in December to 96 percent in September, with a yearly mean of 92 percent. Larger differences in illumination between Windsor and Harrow have been obtained on days of relatively high pollution. The reduction in ultraviolet radiation would be greater than that for visual light.

Measurements of visibility have been made in Detroit with a transmissometer. Reduced light transmittance was found to be associated with winds from directions tending to bring contaminated air from major industrial sources of pollutants to the observation site. The highest visibility occurred when winds were from directions in which were located residential areas and small business establishments.

The adverse effects on property through deposition of smoke and fly ash, the action of acid gases and the soiling of surfaces by aerosol pollutants represent economic losses. This includes damage to fabrics, household equipment, merchandise, buildings, metal products and other exposed materials. It is difficult to place an exact estimate on all the economic effects resulting from contaminated air because of the varied nature of such losses. However, some relative estimates may be made. The cost of smoke damage has been estimated in a number of American cities to vary between $15 and $20 per capita per year. If a $15 estimate were applied to the 3.4 million residents of the Detroit River area, the calculated annual loss due to air pollution would be about $50, 000, 000.

The City of Detroit has undertaken an extensive program of reconstruction and rehabilitation of the downtown area, with the erection of many modern public and office buildings. The replacement of old buildings in the waterfront area by new construction with appropriate park and other landscape development is an important feature of the plan which involves expenditures of hundreds of millions of dollars. Several recreational areas are located in the area and some are along the shores of the Detroit River and on islands in the river. Contamination of the atmosphere of these areas by smoke would detract from their value and desirability.

CONTROL OF POLLUTION FROM VESSELS

Remedial measures are available for the control of atmospheric pollution from vessels. These include training and supervision of operators, proper choice of fuel and changes in equipment. As an example of the latter, 31 vessels which were observed in the Detroit River during the 1957 navigation season that were formerly hand-fired are now fired by underfeed stokers. Their smoke emission performance was greatly improved and generally satisfactory. No serious trouble in operation or maintenance has been reported. Quite a number of vessels have been converted from hand-fired coal-burning to oil-burning, resulting in greatly improved smoke emission performance. Ninety-seven vessels fired by spreader stokers were observed in the Detroit River during 1957. Their smoke emission was generally satisfactory. However, fly ash emission is generally considered to be quite high for spreader stoker fired vessels. It is estimated that approximately 250 hand-fired vessels would have to be converted to either stoker or oil firing to meet reasonable smoke emission standards. This would cost approximately $50,000 for a four-furnace vessel converted to underfeed stoking, providing the presently installed boilers are not required to be replaced. Conversion to oil firing for a four-furnace vessel would entail a cost of $80,000 to $90,000 approximately. For the six-furnace vessel, the installation of underfeed stokers would cost approximately $95,000, whereas the costs of conversion to oil firing would be about $100,000. In individual cases where new boilers are installed at the same time, the total cost per vessel may reach $270,000 or more. At an average cost of about $75,000 per vessel, the above conversion program would entail a total expenditure of about $19,000,000 for 250 vessels.

DISCUSSION OF RECOMMENDATIONS

RECOMMENDATIONS ONE, TWO, AND THREE

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

1. The Governments of Canada and the United States adopt a code prescribing limitations on the emission of air pollutants from vessels plying the Detroit River and standards for their measurement as follows:

a. For all vessels, except hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less:

No smoke, the shade or appearance of which is equal to or darker than No. 2 of the Ringelmann Chart shall be emitted, except that smoke the shade or appearance of which is equal to but not darker than No. 2 of the Ringelmann Chart for a period or periods aggregating not more than 4 minutes in any 30 minutes shall be permitted;

b. For hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less:

No smoke, the shade or appearance of which is equal to or darker than No. 3 of the Ringelmann Chart shall be emitted, except that smoke, the shade or appearance of which is equal to but not darker than No. 3 of the Ringelmann Chart for a period or periods aggregating not more than 9 minutes in any 30 minutes shall be permitted;

c. For the purpose of grading the shade or appearance of smoke, the Ringelmann Chart as published and used by the U.S. Bureau of Mines, shall be the standard, but the use of any other chart or device having shades equivalent to those of the Ringelmann Chart shall be authorized.

2. That this code be applicable to vessels both in transit and at dockside, except where there is local legislation for control of air pollution under which effective action may be taken with regard to vessels polluting the atmosphere.

3. Two years after the official opening of the St. Lawrence Seaway, or at such later time as the two Governments shall determine that such action would be in the best interests of Canada and the United States, the code should be amended by deleting therefrom the exception in favor of hand-fired cargo vessels with a gross cargo-carrying capacity of 3,200 short tons or less.

The Technical Advisory Board has found that pollution of the atmosphere arising from vessels plying the Detroit River is of such magnitude that a reduction is necessary. True, other sources of pollution cause a greater total pollution of the atmosphere, but action has been taken and will continue (and probably increase), which is directed toward the control of these other sources. The location of the vessels in the Detroit River, in close proximity to residential, recreational and civic land uses, lends greater emphasis to the need for pollution control on vessels than if their location were otherwise.

The advances of technology have make it possible to control smoke emissions from vessels by reasonable means. Smoke emission is an indication of inefficient combustion and thus a loss of heating values available from the fuel. In many cases the application of smoke abatement measures to lake vessels results in a financial gain to the vessel owner because of decreased labor costs of firing, decreased labor turnover of firemen because of improved working conditions, somewhat greater vessel cruising speed, and other factors.

However, the Technical Advisory Board believes that, in the case of small cargo-carrying vessels with a capacity of 3, 200 short tons or less, application of smoke control measures which are entirely satisfactory is not to the best interests of all concerened at this time. There are three principal considerations in granting temporary exception to these vessels. The first is the serious, but not yet specifically defined, effect that the opening of the St. Lawrence Seaway will have on the competitive position of these vessels. There is a good possibility that many of these vessels will rate so poorly in their economics of operation in comparison with other vessels that they will be scrapped or sent to other areas. The competition of larger, more modern and efficient vessels, which will compete for business with these vessels after the Seaway opens, may well force such action. Therefore, it does not appear wise to require expenditure of a sizable sum of money to control smoke from vessels which may well be retired in 1959 or shortly thereafter when the Seaway is scheduled to open. The second principal point in granting temporary exception to the smaller vessels is the fact that, in most cases, no saving in labor costs results from installation of stokers or oil firing. This is because the vessels carry only three firemen - one for each eight-hour watch. With the installation of automatic firing, these three men are still required. In the case of larger vessels carrying six firemen when using coal hand-firing, it will be possible to operate with only three firemen after installation of automatic firing equipment, thus saving a substantial sum in labor. Therefore, little or no opportunity is available to the owners of the smaller vessels to recover the costs of new firing equipment except by cutting profits or increasing freight rates. The third reason for granting deferment is the necessity for maintaining the services of these vessels at prevailing freight rates in moving freight to and from Montreal and other lower St. Lawrence ports and Great Lakes ports where the freight is delivered to or received from larger upper lake vessels. These large vessels cannot proceed to Montreal and lower St. Lawrence ports because of their deep draft. It is not to the best interests of the public to require installation of equipment for prevention of smoke at this time, since substantial freight increases would probably result and there would be an adverse effect on the economic position of cargoes carried as well as on the concerned vessel owners.

However, such deferment should not be of indefinite duration, in the interests of those affected by the pollution discharged by these vessels. At present, it is believed that owners of the concerned vessels should be in a position, in not more than two years after the opening of the Seaway, to determine the prospects for future operations and to have either installed equipment which will make satisfactory smoke emission performance possible or to take other steps. However, should some presently unforeseen circumstance occur, such as a long delay in opening the Seaway, a change in this time of deferment may be found desirable in the over-all interests.

This deferment, however, will not constitute permission to discharge smoke which can be prevented by good operating practices and proper fuel specification. Limits of smoke emission which would apply to the excepted vessels during the period of deferment can be met by most vessels if care is taken. The limits recommended are not satisfactory from the pollution control viewpoint but do limit extremely heavy smoke emissions.

The limitations proposed for all vessels (except the smaller hand-fired cargo vessels during the period of deferment) are the same as those published by the American Society of Mechanical Engineers in their information bulletin entitled, "Example Sections for a Smoke Regulation Ordinance" as prepared by the Model Smoke Law Committee (May 1949). They are also the same as the smoke emission limitations in the Detroit and Windsor air pollution control laws and in most of the other smoke abatement laws of other municipalities in the Detroit River area.

The limitations recommended for hand-fired cargo vessels with a gross cargo-carrying capacity of 3, 200 short tons or less during the period of deferment are designed to promote the best feasible smoke emission performance from these vessels without requiring major changes in firing equipment or fuels. The limitations proposed are the same as the No. 3 Objective of the voluntary vessel smoke control program.

The Ringelmann Chart is recommended as the primary standard for grading the density of smoke. No other generally accepted standard is available. However, it is recommended that the use of other devices standardized against the Ringelmann Chart be authorized. Such devices are presently available and others may be developed.

RECOMMENDATIONS FOUR AND FIVE

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

4. The Governments of Canada and the United States by procedures appropriate in each country take action to ensure compliance with the code.

5. The Governments of Canada and the United States, in consultation with Provincial, State, county, township and city governments, develop legal and administrative procedures for dealing with noncompliance with and revision of the code; develop appropriate methods for establishing proof of such noncompliance; study and resolve related questions such as the definition of the jurisdictions of courts concerned with the enforcement of the code, and of extenuating circumstances under which deviations from the code may be permitted.

Local agencies have no feasible means of compelling appearance of vessel captains or other responsible company officials before administrators, hearing bodies, or courts in answer to requests or summonses to do so for the purpose of discussing or trying in court instances of violation of emission standards unless the vessel docks in the area of jurisdiction of the concerned agency or has offices located within the concerned area. It would be unreasonable and unfeasible to require a vessel to come to dockside while in the jurisdictional area of a certain agency. Yet, when the vessel leaves the area of jurisdiction, the legal powers to require court appearance are lost to the enforcement agency. Instances of violation involving foreign flag vessels would be particularly complex and perhaps develop into matters of diplomatic concern. Therefore, it appears logical that the federal governments, with their broad jurisdictional powers, undertake a substantial role in the vessel smoke program.

Since the recommended smoke emission standards given herein may become obsolete, it is desirable to provide some mechanism for making changes to the standards. A procedure simpler than changing federal law would be desirable. Cities have provided for such changes by authorizing administrative or advisory bodies to make such changes and have set out procedures for doing so.

RECOMMENDATIONS SIX AND SEVEN

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

6. The Technical Advisory Board on Air Pollution, as presently constituted for the Detroit-Windsor Reference of January 12, 1949, be relieved of its duties.

7. A Board of Control on Air Pollution be established as soon as possible to serve in an advisory capacity to the Commission in regard to the smoke emission from vessels plying the Detroit River. It would be the duty of this Board to keep the International Joint Commission advised of progress made in the control of air pollution from such vessels; maintain effective liaison with Provincial, State, county, city and other jurisdictions in order to provide such mutual assistance and cooperation as may be appropriate; and on behalf of the commission, until the adoption and implementation of the code, conduct a continuing program of observation and control of vessel smoke emission on a voluntary basis in cooperation with vessel owners and operators and local authorities.

The new board may well have representatives from agencies or groups not represented on the present board. The present Board is felt to have fulfilled its purposes with the submission of this final report.

Continuation of the voluntary vessel smoke control activity is necessary to maintain a constant awareness in the shipping industry of the needs and desires for control of pollution. Such awareness is a contributing factor in maintaining activities directed toward greater utilization of air pollution control techniques and equipment and in preventing a regression to the considerably worse smoke emission situation of six to eight years ago. The implementation of a legal control program may require some considerable time. The voluntary program will be of benefit in the meantime.

RECOMMENDATION EIGHT

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

8. The voluntary control program referred to in recommendation 7 have the following smoke emission objectives for the various classes of fuel-burning equipment on vessels:

MAXIMUM NUMBER OF MINUTES OF SMOKE EMISSION IN ANY 30-MINUTE PERIOD

Objective	Fuel-burning equipment	Minutes at Ringelmann Number				
		1	2	3	4	5
1	Oil-fired, underfeed-stoker-fired and diesel engines	30	4	0	0	0
2	Spreader-stoker-fired	30	30	3	0	0
3	Hand-fired	30	30	9	0	0

The purpose of the voluntary vessel smoke control program is to encourage, by persuasive means, the best smoke emission performance that can be obtained. Improvements in smoke emission performance are brought about by changes in firing equipment or fuels, but often it is a matter of securing actions on the part of vessel owners, captains, and firemen to use existing equipment in such a way that minimum smoke emissions will result. Until vessel owners can be required to make needed major changes, it is most appropriate to establish objectives which can be attained by proper use of existing equipment. Although the number 2 and 3 objectives are not considered ultimate satisfactory performance, they will serve the purposes of the voluntary program. To establish voluntary objectives which are too difficult to achieve might stifle efforts to reach them.

RECOMMENDATION NINE

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

9. Appropriate jurisdictions fronting the Detroit River be encouraged to adopt the limitations of emission of smoke and air pollutants as adopted by the Governments of Canada and the United States, so that vessels in transit and at dockside will be subject to uniform codes.

Ordinarily air pollution emission standards should be tailored to meet the varying conditions prevailing in each locality. However, in the case of vessels which will be operating within a large number of jurisdictions, it is desirable to have only one set of well chosen standards. It would be confusing to shipping interests to be subject to different requirements at various points along the shipping lanes. It would also complicate the problem of design and selection of equipment and fuels that might be required to meet smoke emission limitations.

Existing smoke emission standards in cities located on the Detroit River are already reasonably uniform. Only a few modifications would be required to bring them into agreement with the limitations recommended herein.

RECOMMENDATION TEN

The Technical Advisory Board respectfully recommends to the International Joint Commission that:

10. The costs incurred for vessels to meet these codes or the voluntary smoke emission objectives be borne solely by the owners of such vessels.

Since the excessive emission of smoke by vessels creates unsatisfactory conditions it is reasonable that the owners of such vessels provide for measures that will correct them.

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